Helwan University
Faculty of Engineering
Civil Department



تحليل أداء المباني الخضراء باستخدام تطبيقات نمذجة البناء المتكاملة BIM

"Sustainable Buildings Performance Analysis Using BIM Applications"

A Thesis Submitted to

Helwan University – Faculty of Engineering – Civil Department

In partial fulfillment of the requirements for the degree of Master of Science in Project Management - Sustainable Development

By

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STATEMENT

"We do not inherit the earth from our ancestors...we borrow it from our children" (Berry 1971)

To My Parents

ABSTRACT

Sustainable development, of which construction is a part, has been recognizably divided into energy use reduction, industrial development, climate change, water conservation, recycling and waste reduction, sustainable procurement of materials, transport strategies and biodiversity. The sustainable building or structure is one that satisfies environmental, social and economic concerns in a balanced way. With the increasing demand for sustainable buildings' design, the whole building energy simulation tools are extensively involved in the design process for saving energy and improving building performance. On the other hand, Building Information Modeling - BIM is utilized as a simulation technique for various sustainability practices like; building location, orientation, sun- path analysis, thermal properties of materials, heating and cooling loads, day-lighting and ventilation. However, sustainability is more concerned with all environmental aspects and the whole building design rather than energy simulation. The aim of this research is to introduce a simplified approach for BIM-based simulation technique as a tool for pre-assessment of sustainable buildings' design. The proposed method helps project development team to conduct the required evaluation of design alternatives according to a specified Green Building Rating system. Moreover, a case study was applied on the rating system Leadership in energy and environmental design - LEED to investigate the configuration of using BIM in accordance with the LEED rating system and producing an easy to be handled assessment template that measures compliance with sustainable requirements and measures the potential points than the design can achieve.

KEYWORDS:
Green Buildings, BIM-based Sustainability, Building Performance Analysis, Energy Simulation, Building Energy Performance

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List of Abbreviations

AEC Architecture, Engineering and Construction

AGC American General Contractors

ANSI American National Standards Institute

API Application Programming Interface

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

BEECs Building Energy Efficiency Codes

BEPAC Building and Environmental Performance Assessment Criteria

BIM Building Information Modeling

BREEAM Building Research Establishment Environmental Assessment Method

CAD Computer-Aided Drafting

CaGBC Canadian Green Building Council

CASBEE Comprehensive Assessment System for Building Environmental Efficiency

CIB Conseil International du Bâtiment

DBMS Data Base Management System

DDX Design Data Exchange

DGNB Deutsche Gesellschaft für Nachhaltiges Bauen

DOE	U.S. Department of Energy
DXF	Drawing eXchange Format
DWG	Drawing
EA	Energy & Atmosphere
EGBC	Egyptian Green Building Council
EGPRS	Egyptian Green Pyramid rating System
EI	Environmental Impact
EISA	Energy Independence and Security Act of 2007
EPA	US Environmental Protection Agency
GBCS	Green Building Certification System
GBCs	Green Building Councils
GBCI	Green Business Certification Institute
GBI	Green Building Initiative
gbXML	Green Building eXtensible Markup Language
GHG	Greenhouse Gases
GSA	General Services Administration
HVAC	Heating, Ventilation & Air Conditioning
IAS	International Accreditation Service
IAQ	Indoor Air Quality

ID	Innovation in Design
IECC	International Energy Conservation Code
IEQ	Indoor Environmental Quality
IES<VE>	Integrated Environmental Solutions <Virtual Environment>
IFC	Industry Foundation Class
IgCC	International Green Construction Code
IGES	Initial Graphics Exchange Specification
iiSBE	International Initiative for a Sustainable Built Environment
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design
LEED-NC	LEED for New Construction
LGBC	Lebanon Green Building Council
MADM	Multi Attribute Decision Making
MCDM	Multiple Criteria Decision Making
MODM	multi objective decision making

MENA	Middle East and North Africa
MEP	Mechanical, Electrical and Plumbing
MR	Material& Resources
NEPA	National Environmental Policy
NIBS	National Institute of Building Science
NIST	National Institute of Standards and Technology
ODBC	Open Database Connectivity
SGBF	Saudi Green Building Forum
SS	sustainable site
UNEP-SBCI	United Nations Environment Programme - Sustainable Buildings & Climate Initiative
USEPA	United States Environmental Protection Agency
USGBC	United States Green Building Council
WCED	World Commission on Environment and Development
VOC	Volatile Organic Compound
WBDG	Whole Building Design Guide
WBS	Work Breakdown Structure
WE	water efficiency
WorldGBC	World Green Building Council
zEPI	Zero Energy Performance Index

CHAPTER 1

Introduction

1.1 General overview

Building Information Modeling BIM, provides more accurate and integrated documentation, less confusion and rework, this results in saving time, cost and efforts. The use of BIM to provide data for energy performance evaluation and sustainability assessment is defined as "Green BIM". Large design organizations adopt this approach to enable integrated design, construction and maintenance towards Net Zero Energy buildings. Green BIM includes Building Energy Modelling dealing with the project energy performance to optimize energy efficiency during the Project life cycle. During the design phase, project team can ensure that sustainable compliance can be realized beside the technical and economic requirements. Thus, BIM can provide information to determine the credit points assigned to specified levels of sustainability rating systems, (Sebastiano Maltese 2016). Moreover, decision making in the early design stage impacts on the performance and cost-effectiveness of the buildings significantly, (Ajla Aksamija 2012). Project owner and design team need a third-party verification to certify the project as a sustainable building. In order to deal with an authorized third party and go through the certification process, it takes a lot of time, effort, and cost. The owner and the design team may prefer if they have a prior verification tool for saving design time and cost. In addition, the third party may use the same tool in the integration design process with concerned parties. Meanwhile, the main issue in the whole building design approach is to have an accurate and accessible source of information. Integrated design helps to

engage all consultants and stakeholders at early stages of the project. Whether, contractually allowed for this dynamic interface at early stages or not, architects have increasing responsibility to address energy and environmental factors in the conceptual stages of design projects, (Quinn, 2013). LEED, BREEAM, CESBA and other rating systems, are only a certification to be achieved at the end of the construction. Their strong connection with design tools boosts for a solid integration with BIM. Using the Industry Foundation Classes (IFC) protocol, in combination with defined procedures and tools, will allow for a better data extraction and elaboration, it is providing more reliable results with less effort, (Sebastiano Maltese 2016). This research introduces a simplified approach, which help the concerned parties to take good decisions in early design stage related to sustainable design targets to benefit from the advantages of the information modeling revolution. In addition, the research surveys the specialists' opinions for the best practices and the effects of the BIM-simulating approach on Architecture, Construction and Engineering, AEC market.

1.2 Research Motivation

The architectural scheme phase is the key to building performance optimization and it should impart great importance on the shape control and internal logic during the parametric design process. However, as it lacks the aided design tools for parameterization design process and features during the scheme design (Borong Linn March 2013). Studies indicate that lately, the demand for sustainable buildings with minimal environmental impacts is increasing. The construction industry today needs to adopt new approaches for building design to reduce pressures on the environment. An example of these is the green building approach. Incorporating sustainable principles at the conceptual stage is attained by using sustainable design in which designers

need to identify associated materials and components based on the selected green building certification system (Jalaei 2015). Among the attributes that have acted upon this research field:

- Save time and efforts of rework related to green building certification process during design phase.
- The lack of the implementation of construction, energy and environmental regulations and codes in MENA area.

The motivation for this research is to support the following principle aspects, which are; (1) current environmental challenges in MENA area toward the targets of 2030 vision, (2) the lack of sustainability awareness in the MENA communities, and (3) the economic challenges that MENA area is facing.

1.3 Research Objectives

The use of building information modeling (BIM) has provided a means of increasing total project quality, providing accurate quantity take-off, improving scheduling, and consequently diminishing total project contingencies and costs. Although BIM is a recent development technique, a lot of research has been conducted in order to further enhance the capabilities of BIM in design and construction. However, there is a little research done on the effect that BIM has on sustainable construction practices (Bynum and Olbina 2013). The main objective of this research is investigating to what extent the integration between BIM and LEED certification process can be helpful. The study attempts to outline a conceptual framework for BIM-LEED integration. This conceptual framework indicates the various BIM tools and add-ins which can support and enhance the manual process of calculating credits for LEED certification. The main objectives of the research are:

- Check the ability of BIM-Based Simulation tools to measure the credit categories of a specific green building rating system using a simple workflow,
- Calculate the potential LEED v4 Point could be achieved directly, semi directly and indirectly by BIM software,
- Develop a simplified template can be utilized by the BIM software,
- Provide green building pre-assessment tool for the design team in order to save time and efforts of green building certification process.

1.4 Research Methodology

This research is carried out based on gathering information from past relevant researches as a literature review, for integration between BIM-Based sustainability software and green building design in order to find out the current situation and answer the question, how can the BIM software support design process to achieve LEED credits? After literature review, the research compromised an assessment excel sheet that contain LEED® v4 credit categories checklist. The purpose of excel sheet is to classify the required data to be extracted from BIM software, whether direct or semi direct or indirect. A case study was undertaken to achieve the targeted LEED® v4 certification for the selected verification model of the taken case study “Maisalon Hotel” project, which located at Northern Province of Saudi Arabia. By applying, the pre-designed checklist in parallel with proposed improbability framework on the BIM model to measure the potential green building credits could be achieved under LEED® v4’s credit categories. Finally, the research proposes a flowchart for sub-LEED credit categories. Every checked credit category exports the potential credits to a particular column in the final credits sheet either automatically or manually

CHAPTER 2

Culture of Sustainability

The word origin of sustainability [suh-stey-nuh-bil-i-tee]; the ability to be sustained, supported, upheld, or confirmed. In environmental Science; the quality of not being harmful to the environment or depleting natural resources, and thereby supporting long term ecological balance: The committee is developing sustainability standards for products that use energy (Dictionary.com 2018). In 1987, a report was developed on Sustainable Development in the World Commission on Environment and Development (WCED), identified later as the 'Brundtland Report', named according to the chair of the commission, G.H. Brundtland (Glavinich 2008). According to WCED, Sustainable development is defined as, *'Humanity has the ability to make development sustainable- to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs' (1987).* The National Environmental Policy Act of 1969 (NEPA) committed the united states to sustainability, declaring it a national policy "To create and maintain conditions under which humans and nature can exist in productive harmony، that permit fulfilling the social، economic and other requirements of present and future generations." (EPA 2018).

2.1 Sustainability and Green Building

Sustainability is not a one-time treatment or product. Instead, green building is a process that applies to buildings, their sites, their interiors, their operations, and the communities in which they are situated. The process of green building flows throughout the entire life-cycle of a project, beginning at the inception of a project idea and continuing seamlessly until the project reaches the end of its life and its parts are recycled or reused (Erdman 2014).

Sustainability and “green,” often used interchangeably, are about more than just reducing environmental impacts. Sustainability means creating places that are environmentally responsible, healthful, just, equitable, and profitable. Greening the built environment means looking holistically at natural, human, and economic systems and finding solutions that support quality of life for all (Erdman 2014). The terms like; high performance, green, and sustainable construction often are used interchangeably. However, the term "sustainable construction" most comprehensively addresses the ecological, social, and economic issues of a building in the context of its community. In 1994, the Conseil International du Bâtiment, CIB defined sustainable construction as; “creating and operating a healthy built environment based on resource efficiency and ecological design”. CIB articulated seven principles of Sustainable Construction that ideally would inform decision makers during each phase of the design and construction process, continuing throughout the building’s entire life cycle, Table 2-1 list the seven Sustainable building principles (Kibert 2016).

Table 2-1: Sustainable building principles

Principles of Sustainable Construction
1. Reduce resource consumption (reduce).
2. Reuse resources (reuse).
3. Use recyclable resources (recycle).
4. Protect nature (nature).
5. Eliminate toxics (toxics).
6. Apply life-cycle costing (economics).
7. Focus on quality (quality).

2.2 Why is Sustainable/green building necessary?

Buildings and communities, including the resources used to create them and the energy, water, and materials needed to operate them, have a significant effect on the environment and human health (Erdman 2014). For example, In the United States, buildings account for:

- 14% of potable water consumption
- 30% of waste output
- 40% of raw materials use
- 38% of carbon dioxide emissions
- 24% to 50% of energy use
- 72% of electricity consumption

2.3 Climate Change, Present and Future

A certain amount of continued warming of the planet is projected to occur as a result of human-induced emissions to date; another 0.5°F increase would be expected over the next few decades even if all emissions from human activities suddenly stopped, although natural variability could still play an important role over this time period. However, choices made now and in the next few decades will determine the amount of additional future warming. Beyond mid-century, lower levels of heat-trapping gases in scenarios with reduced emissions will lead to noticeably less future warming. Higher emissions levels will result in more warming, and thus more severe impacts on human society and the natural world (Melillo 2014). Confidence in projections of future climate change has increased. The wider range of potential changes in global average temperature in the latest generation of climate model simulations used in the Intergovernmental Panel on Climate Change's (IPCC) current assessment – versus those in the previous

assessment – is simply a result of considering more options for future human behavior. For example, one of the scenarios included in the IPCC's latest assessment assumes aggressive emissions reductions designed to limit the global temperature increase to 3.6°F (2°C) above pre-industrial levels. This path would require rapid emissions reductions (more than 70% reduction in human-related emissions by 2050, and net negative emissions by 2100. Climate Science sufficient to achieve heat-trapping gas concentrations well below those of any of the scenarios considered by the IPCC in its 2007 assessment. Such scenarios enable the investigation of climate impacts that would be avoided by deliberate, substantial reductions in heat-trapping gas emissions Figure 2-1 shows the ten indicators of warming world (Melillo 2014).

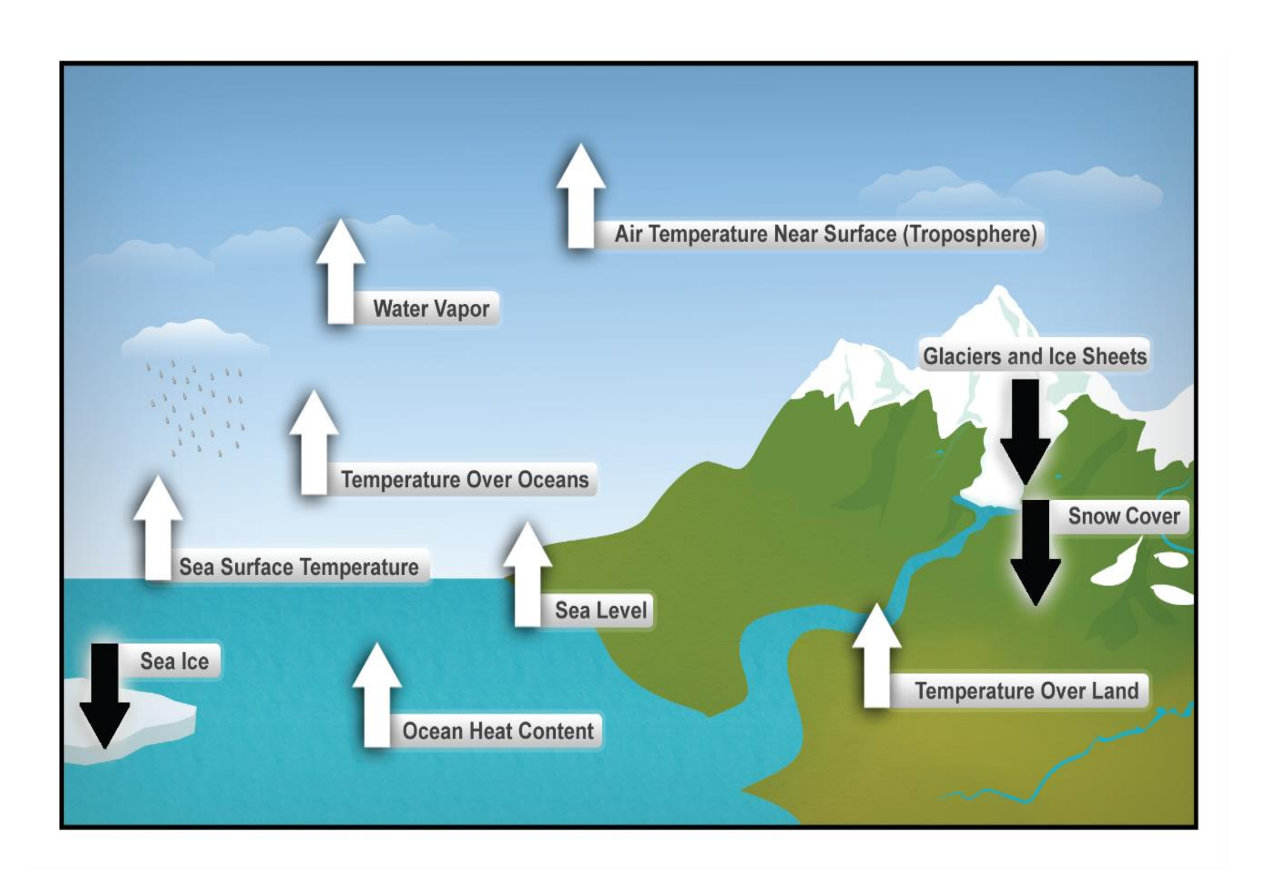
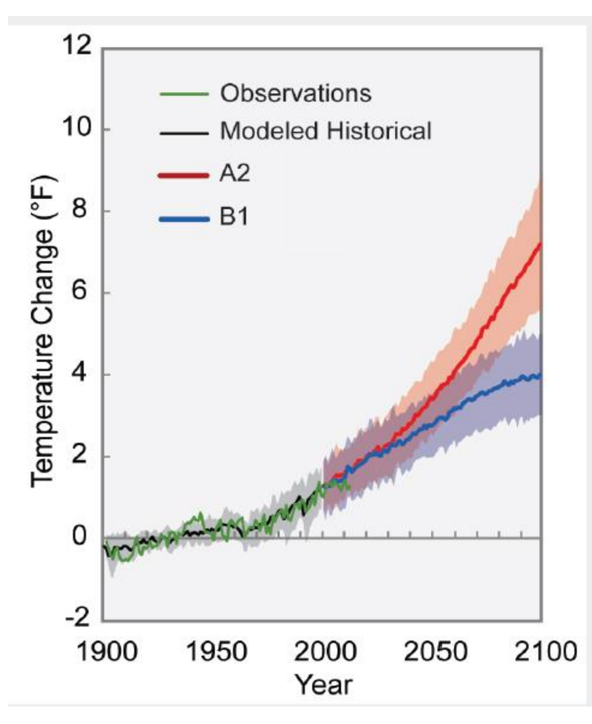


Figure 2-1: Ten Indicators of Warming World

Evidence for climate change abounds, from the top of the atmosphere to the depths of the oceans. Scientists and engineers from around the world have meticulously collected this evidence, using satellites and networks of weather balloons, thermometers, buoys, and other observing systems. Evidence of climate change is also visible in the observed and measured changes in location and behavior of species and functioning of ecosystems. Taken together, this evidence tells an unambiguous story: the planet is warming, and over the last half century, this warming has been driven primarily by human activity (Melillo 2014). The amount of warming projected beyond the next few decades is directly linked to the cumulative global emissions of heat-trapping gases and particles. By the end of this century, a roughly 3°F to 5°F rise is projected under a lower emissions scenario, which would require substantial reductions in emissions (referred to as the "B1 scenario"), and a 5°F to 10°F rise for a higher emissions scenario assuming continued increases in emissions, predominantly from fossil fuel combustion (referred to as the "A2 scenario"). These projections are based on results from 16 climate models that used the two emissions scenarios in a formal inter-model comparison study. The range of model projections for each emissions scenario is the result of the differences in the ways the models represent key factors such as water vapor, ice and snow reflectivity, and clouds, which can either dampen or amplify the initial effect of human influences on temperature. The net effect of these feedbacks is expected to amplify warming (Melillo 2014). Figure 2-2 shows the different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature.



Different amounts of heat-trapping gases released into the atmosphere by human activities produce different projected increases in Earth's temperature. The lines on the graph represent a central estimate of global average temperature rise (relative to the 1901-1960 average) for the two main scenarios used in this report. A2 assumes continued increases in emissions throughout this century, and B1 assumes significant emissions reductions, though not due explicitly to climate change policies. Shading indicates the range (5th to 95th percentile) of results from a suite of climate models. In both cases, temperatures are expected to rise, although the difference between lower and higher emissions pathways is substantial. (Figure source: NOAA NCDC / CICS-NC).

Figure 2-2: Projected Global Temperature Change. Source, the Third National Climate Assessment (Melillo 2014)

2.4 Cost of Green Buildings

Research on climate change suggests that small improvements in the sustainability of buildings can have large effects on energy efficiency in the economy. Increased awareness of global warming and the extent of greenhouse gas emissions in the real estate sector have increased attention to green building, the attributes rated for both thermal efficiency and sustainability contribute to premiums in rents and asset values. Even among green buildings, increased energy efficiency is fully capitalized into rents and asset values. (Eichholtz 2010). In all types of construction projects, regardless if they are traditional or green, there are 2 basic and common types of costs related to the project: the project's hard costs and soft costs. With LEED, a third cost element, life cycle costing, is used for the purpose of factoring into the analysis the true value of a building over its lifetime (Studio 2014). The Davis Langdon 2006 study shows essentially the same results as 2004: there

is no significant difference in average costs for green buildings as compared to non-green buildings. Many project teams are building green buildings with little or no added cost, and with budgets well within the cost range of non-green buildings with similar programs in many areas of the country, the contracting community has embraced sustainable design, and no longer sees sustainable design requirements as additional burdens to be priced in their bids. Many projects are achieving certification through pursuit of the same lower cost strategies, and that more advanced, or strategies that are more expensive are often avoided. Most notably, few projects attempt to reach higher levels of energy reduction beyond what is required by local ordinances, or beyond what can be achieved with a minimum of cost impact (Morris 2007). "The Construction Cost of LEED" study conducted by Chad Mapp and his team demonstrated the costs associated with the LEED projects were always within the overall range of the non-LEED projects. Within sub groups, it was found that for the project team with less experience, soft costs for the LEED project tended to be just above the range of the non-LEED range. For the project team with more documented experience with LEED, costs associated with LEED tended to be at the middle or low end of the range established using similar non-LEED buildings. This was an unexpected, but interesting result, which demonstrated how the project team's experience with LEED could affect project costs. The results showed that as the project team gained more experience with LEED requirements and certification, there was a decline in costs associated with LEED certification (Chad Mapp 2011).

2.5 Green Building Benefits

As John Elkington stated, "*Business is sustainable when it lives up to the triple bottom line of economic prosperity, environmental quality and social justice*" (Elkington 1998). The benefits of green building focus around three dimensions of sustainability (Studio 2014):

Economic Benefits

- Reduce operating costs
- Create, expand, and shape markets for green product and services
- Improve employee satisfaction and productivity
- Optimize life cycle economic performance

Social Benefits

- Enhance occupant comfort and health
- Heighten aesthetic qualities
- Minimize strain on local infrastructure
- Contribute to overall quality of life

Environmental Benefits

- Enhance and protect biodiversity and ecosystems
- Improve air and water quality
- Reduce waste streams
- Conserve and restore natural resources



Figure 2-3: The triple bottom lines

2.6 UNEP-United Nations Environment Programme - Sustainable Buildings & Climate Initiative (UNEP-SBCI)

UNEP-SBCI is a partnership between the private sector, government, non-government and research organizations formed to promote sustainable buildings globally. Now in its fifth year, we have nearly doubled our membership over this past year to reach over forty members representing these constituents. UNEP-SBCI also partners with the Marrakech Task Force on Sustainable Building & Construction, the UNEP Finance Initiative (FI) Property Working Group (PWG), the UNEP/SETAC Life-Cycle Initiative (LCI), the International Initiative for a Sustainable Built Environment (iiSBE), the UNESCO Chair for Sustainable Construction and the Council for Building Research and Innovation (CIB). (UNEP-SBCI 2010).

- **Mission:** to present a common voice of building sector stakeholders on buildings and climate change, drawing on UNEP's unique capacity to provide a global platform for collective action.
- **Goals:**

1. Provide a common platform for the stakeholders: Provide a global platform for dialogue and collective action from buildings sector stakeholders to address sustainability issues of global significance, especially climate change;
2. Establish baselines: Establish globally acknowledged baselines based on the life cycle approach, with a first focus on energy efficiency and CO2 emissions;
3. Develop tools and strategies: Develop tools and strategies for achieving a wide acceptance and adoption of sustainable building practices throughout the world; and

4. Demonstrate through pilot projects: Participate in, influence and support policy developments recognizing the role of buildings for mitigation and adaptation to climate change at local, national and/or global levels.

- **Objectives:** To meet these goals, UNEP-SBCI shall implement its work plan and budget focused on the following corresponding objectives:

1. Outreach and membership activities to raise awareness of the significant opportunities for engaging the building sector in tackling climate change and increasing participation in UNEP-SBCI.
2. Frame a Common Language for performance assessment of energy efficient & low carbon buildings, as a basis for consistent global reporting of building related greenhouse gas emissions.
3. a Contribute to UNFCCC Negotiations by providing direct advice and support to policy-makers at all levels on mitigating building-related greenhouse gas emissions.
3. b Support Policy Development relating to sustainable buildings through funding research that provides policy scenarios for achieving very high-efficiency and low-greenhouse gas emission buildings, with a focus on developing countries.
4. Facilitate the Pilot of Tools at city, portfolio and individual building levels to build baselines of performance by building type and climate region.

2.7 The Sustainable Buildings (SB) Index

The need for a common language and definition for sustainable buildings is widely recognized within the building sector. While some countries have defined sustainable buildings through national rating systems and legislation,

most countries do not yet have such references. Without global consensus, the definition of basic issues, indicators, and metrics and the costs and benefits associated with sustainable buildings, tend to vary. This is causing confusion in the market, persistent inaccurate perceptions of political or financial risks, and undermining efforts to fully implement sustainable building practices. This issue has been the core to UNEP-SBCI's mission since its inception in 2006. Upon receipt of three key background reports in December 2008, the membership and Think Tank representatives proposed developing an index of common metrics, based on a life-cycle approach that could be used to report on progress made by various countries in addressing key building-related sustainability issues. In 2009, the Initiative focused on the highest-ranking core global issue of climate change and convened two meetings of international organizations to reach consensus on a common carbon metric for the building sector. This was achieved and the Common Carbon Metric was released at COP15 on December 11, 2009. The SB Index shall provide a globally consistent framework to understand, measure, report, and verify actual building performance on core sustainability issues, particularly in developing countries. The Index is envisaged as a tool for generating a global annual report on progress made by jurisdictions in improving the sustainability of buildings. The Index is not intended to be a rating system. Nevertheless, rather intended to steer and focus building industry stakeholders on the primary issues agreed upon by the leaders of this sector. The Index shall focus on measurable, reportable, and verifiable indicators, be applicable to existing residential and non-residential buildings and facilitate both top-down and bottom-up aggregation of the performance of building stock (Initiative. 2010). The Index shall include aspects of the buildings' impact and benefits with regards to the categories of concern noted below:

- Energy Efficiency & Greenhouse Gas Emissions (EE/GHG);
- Water;
- Materials (consumption, scarcity, life-cycle and waste generation);
- Biodiversity;
- Social Issues (Indoor Environment); and
- Economic Considerations.

2.8 Architecture 2030 Challenge

Buildings are the major source of global demand for energy and materials that produce byproduct greenhouse gases (GHG). Slowing the growth rate of GHG emissions and then reversing it is the key to addressing climate change and keeping global average temperature below 2°C above pre-industrial levels. To accomplish this, Architecture 2030 issued the 2030 Challenge asking the global architecture and building community to adopt the following targets:

- All new buildings, developments and major renovations shall be designed to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 60% below the regional (or country) average for that building type.
- At a minimum, an equal amount of existing building area shall be renovated annually to meet a fossil fuel, GHG-emitting, energy consumption performance standard of 60% of the regional (or country) average for that building type.
- The fossil fuel reduction standard for all new buildings and major renovations shall be increased to:

70% in 2015

80% in 2020

90% in 2025

Carbon-neutral in 2030 (using no fossil fuel GHG emitting energy to operate).

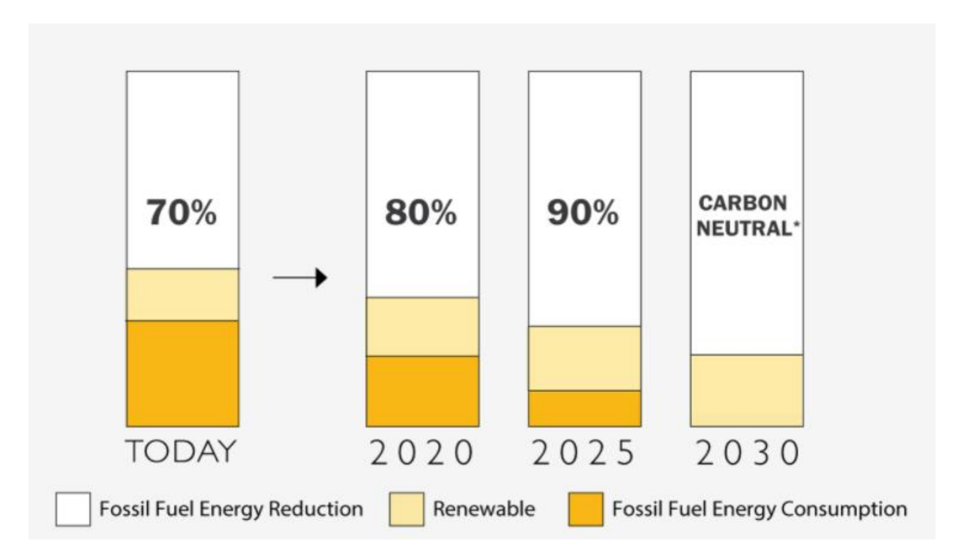


Figure 2-4: 2030 Challenge, (©2015, 2030, Inc./Architecture 2030 Challenge)
* Carbon Neutral (Using no fossil fuel GHG-emitting energy to operate).

Architecture 2030 Challenge has been adopted and supported by numerous professional organizations and over a thousand design firms. By designing and insuring that their projects meet and exceed the 2030 Challenge targets these firms are providing their clients with the best performing and highest-quality buildings possible for little to no additional cost. These adopters are also able to take advantage of the federal, state and local incentives for those projects that achieve the 2030 Challenge targets, as well as lead the professions as national legislation is implemented that incorporates the 2030 Challenge targets into building codes (Architecture2030 2018).

2.9 Zero Energy Performance Index (zEPI)

Zero Energy Performance Index (zEPI) is a value that represents the ratio of energy performance of a proposed building design compared to the average energy performance of buildings with similar occupancy and climate types, benchmarked to the year 2000. It is the ratio of a proposed building's EUIp to

the EUI of a baseline or reference building model, multiplied by 100 to give a scalar value, which can range from zero (for a zero energy building) to 100 (for a building that uses the same amount of energy as the baseline model). The lower the value, the better the energy performance. The 2012 International Energy Conservation Code (IECC) requires a zEPI of 57; the 2012 International Green Construction Code (IgCC) requires a zEPI of 51, which represents a 10% increase in efficiency over the 2012 IECC. Understanding the zEPI and its implications are necessary for establishing appropriate energy consumption goals for buildings designed and constructed under the new IgCC. Additionally, understanding the implications of design choices on zEPI for a project will help the design team to design to an energy budget and to succinctly communicate design ramifications to interested parties, such as the client, financers, and donors (AIA 2012).

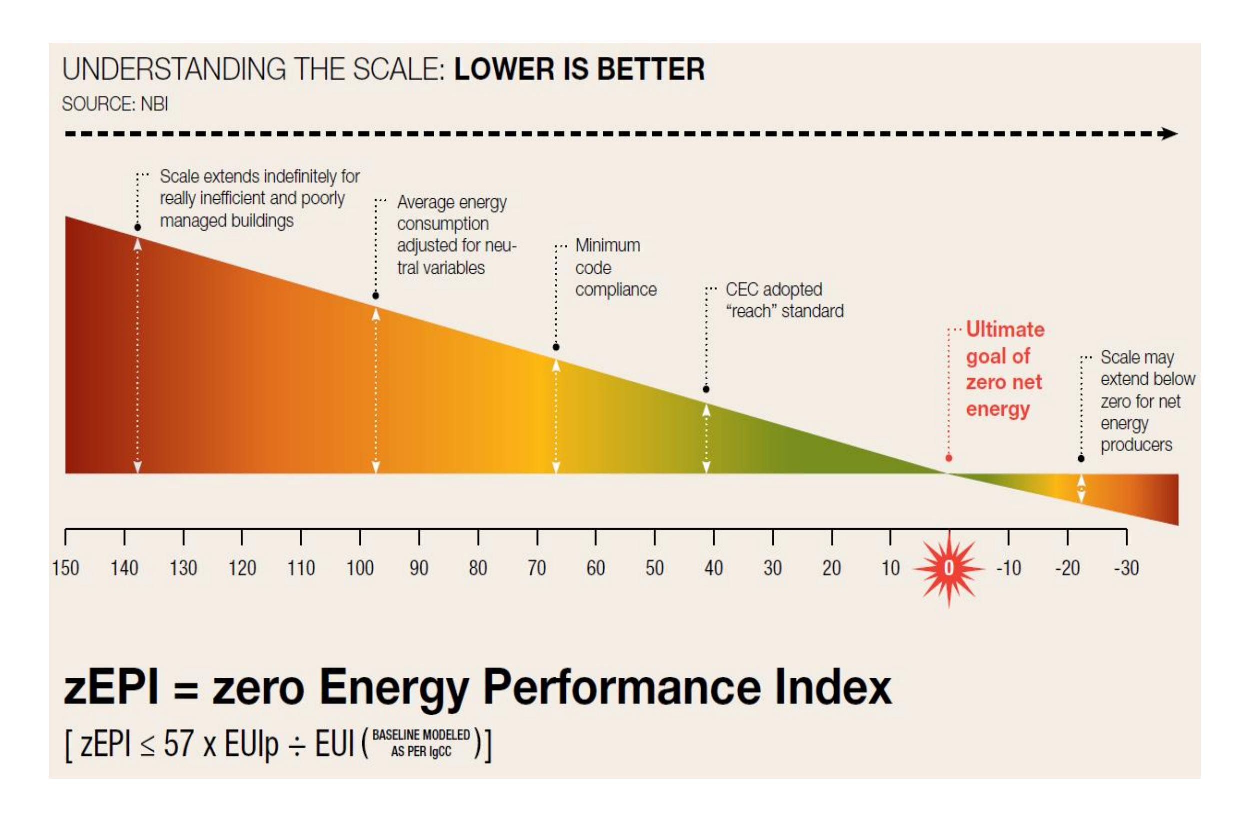


Figure 2-5: zero Energy Performance Index (AIA 2012)

2.10 2030 Design Data Exchange (DDx)

Measuring progress on carbon neutrality is a complex task that can take time away from firm capacity. AIA helped develop the 2030 Design Data Exchange (DDx) to make it easier and faster to record data, get results and advance AEC firms performance with actionable information. The confidential, easy-to-use DDx AIA allow firms to pinpoint best practices and anonymously compare project performance and beyond. The research tool allows to compare projects of similar type, size, climate and a host of other attributes across the 2030 portfolio. AIA developed the DDx with support from the US Department of Energy and in partnership with Architecture 2030 and the US Environmental Protection Agency—and with guidance from a diverse group of experienced 2030 firm users (AIA 2018).

2.10.1 Types of projects to report

- projects in an active design phase including conceptual, schematic, design development or construction document phases
- architectural projects with minimum scope that include HVAC system modifications or substantial envelope modifications
- interiors-only projects that include lighting design
- projects in the construction administration phase, if design changes triggered revisions to either the energy model or the code compliance documentation
- master planning projects
- international projects (see special guidance)

2.11 World Green Building Council

The World Green Building Council is a network of national green building councils in more than one hundred countries, making it the world's largest

international organization influencing the green building marketplace. The WorldGBC's mission is to strengthen green building councils in member countries by championing their leadership and connecting them to a network of knowledge, inspiration and practical support. Green building councils are member-based organizations that empower industry leaders to effect the transformation of the local building industry toward sustainability. With one hundred thousand buildings and almost one billion square meters of green building space registered, the influence and impact of this global network is a significant force for social and environmental change.

2.11.1 Green Building Councils

Green Building Councils are independent, non-profit organizations include organizations working in the building and construction industry. As members of World Green Building Council (WorldGBC), they work to develop green building in their own countries, as well as cooperating with other green building councils to achieve environmental, economic and social goals on a larger, global scale Table 2-2 shows the World Green Building Council members classification. Figure 2-6 shows WorldGBC members distribution ratio and Figure 2-7 show the World Green Building Councils distribution around the world. In addition, Figure 2-7 and Figure 2-8 illustrate GBCs distribution within five geographical areas called regional networks. There are currently seventy-four members around the world, each at different stage of their own green building journey. There are three membership levels for Green Building Councils:

Established: a fully developed and operational organization that is running impactful green building programs of work, delivering change on a national level, and embracing best practice governance, accountability and transparency.

- **Emerging:** a membership which has a strong foundation, such as an elected board and staff to manage day-by-day operations. It is expected to progress to Established status within 24 months.
- **Prospective:** an organization at the early stages of developing but has put in place a comprehensive strategy on how it will operate and advance green building in its country. It is expected to progress to Emerging status within 24 months, World-GBC, 2017.

Table 2-2: World Green Building Council Members Classification (World-GBC, 2017)

Membership	**(Prospective)**	**(Emerging)**	**(Established)**	**Potential) (future**
GB Councils	**30**	**12**	**32**	**33**
Total No. of Organizations	**74**			**33**

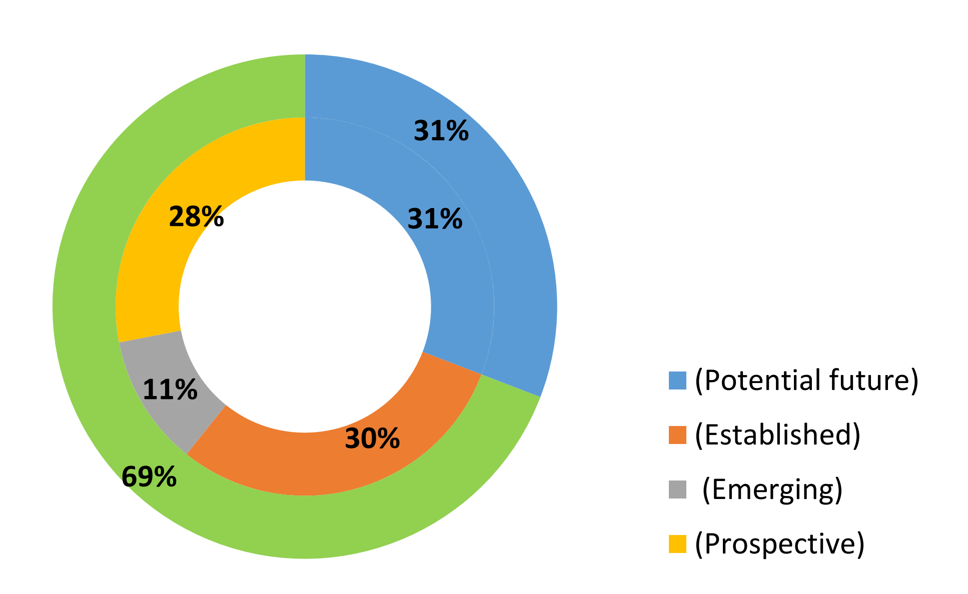


Figure 2-6: World-GBC Members distribution ratio, (World-GBC, 2017)

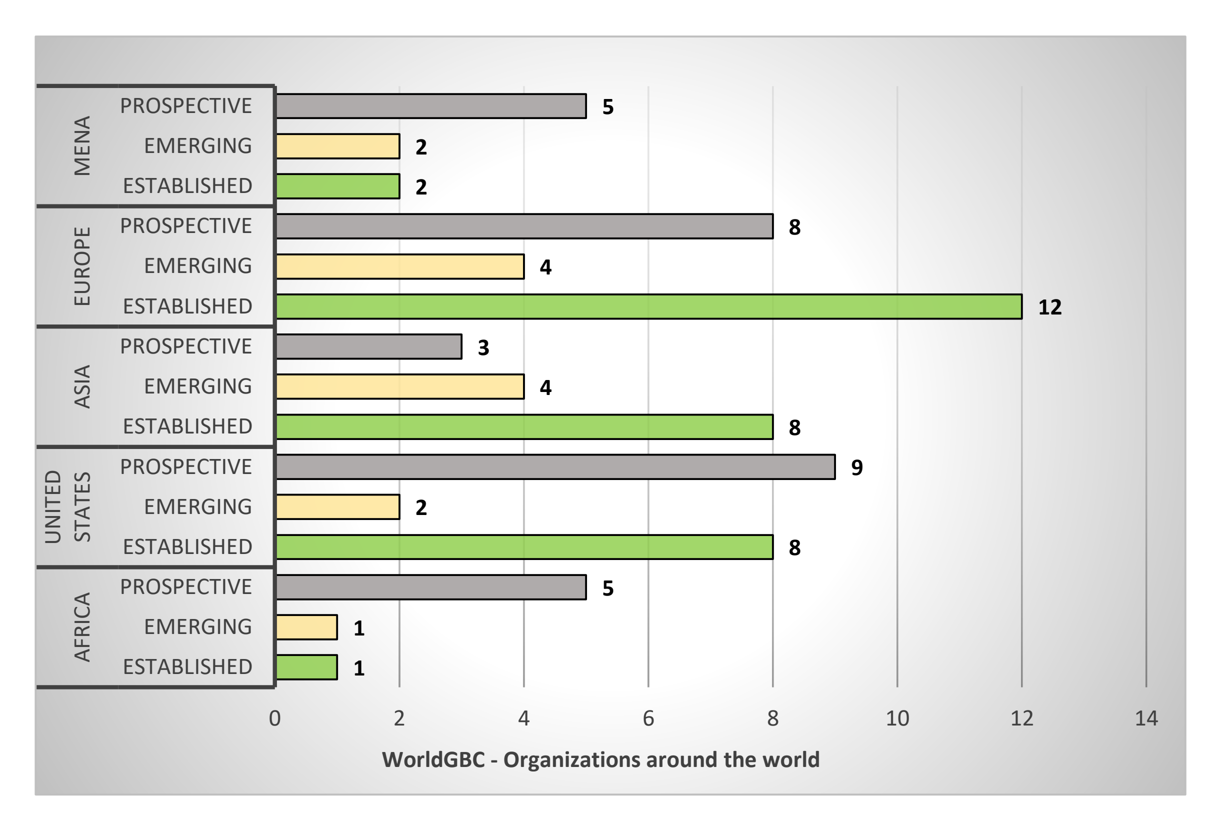


Figure 2-7: World-GBC - Organizations distribution around the world

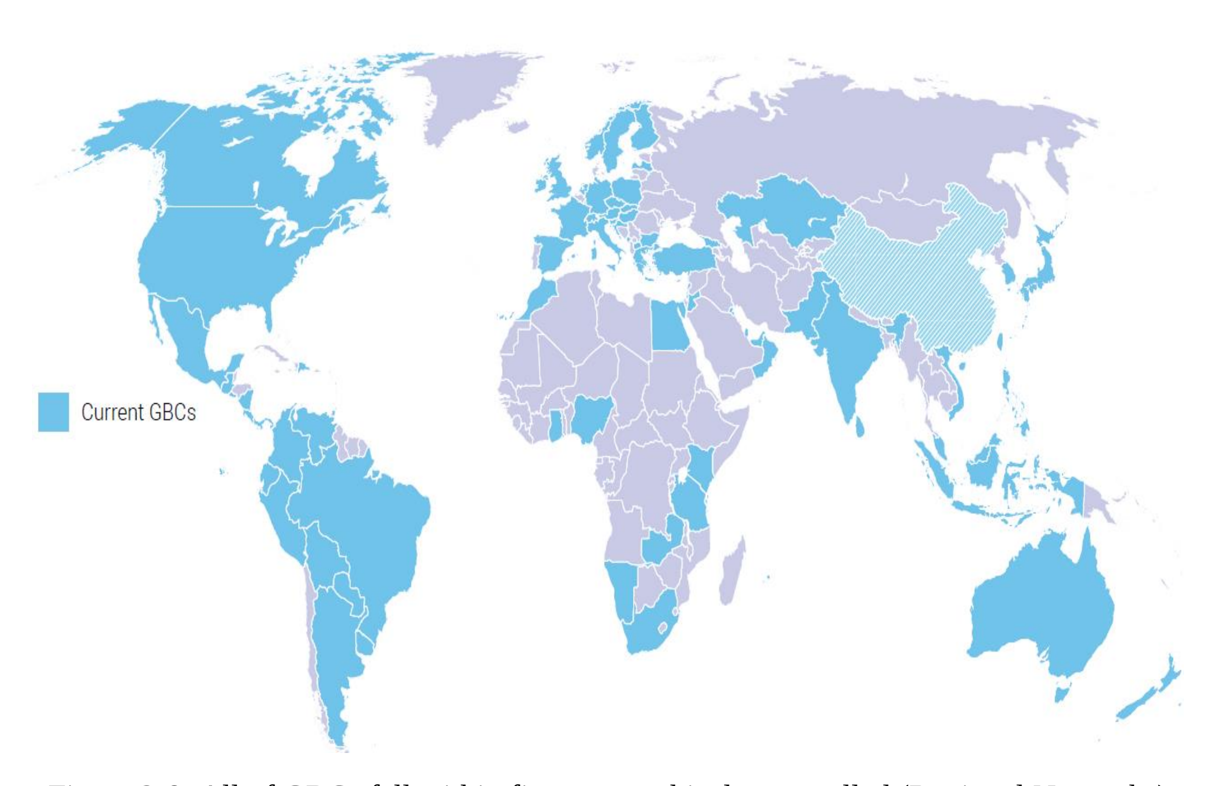


Figure 2-8: All of GBCs fall within five geographical areas called (Regional Networks)

2.11.2 Green building assessment and certification systems

The contemporary high-performance green building movement was sparked by finding answers to two important questions: What is a high-performance green building? How do we determine if a building meets the requirements of this definition? The first question is clearly important having a common understanding of what comprises a green building is essential for coalescing effort around this idea. The answer to the second question is to implement a building assessment or building rating system that provides detailed criteria and a grading system for these advanced buildings (Kibert 2016). The breakthrough in thinking and approach first occurred in 1989 in the United Kingdom with the advent of a building assessment system known as BREEAM (Building Research Establishment Environmental Assessment Method). BREEAM was an immediate success because it proposed both a standard definition for green building and a means of evaluating its performance against the requirements of the building assessment system. BREEAM represented the first successful effort at evaluating buildings on a wide range of factors that included not only energy performance but also water consumption, indoor environmental quality, location, materials use, environmental impacts, and contribution to ecological system health, to name but a few of the general categories that can be included in an assessment. To say that BREEAM is a success is a huge understatement because over 1 million buildings have been registered for certification and about 200,000 have successfully navigated the certification process. Canada and Hong Kong subsequently adopted BREEAM as the platform for their national building assessment systems, thus providing their building industries with an accepted approach to green construction. In the United States, the USGBC developed an American building rating system with the acronym LEED. When launched

as a fully tested rating system in 2000, LEED rapidly dominated the market for third-party green building certification. Similar systems were developed in other major countries: for example, CASBEE (Comprehensive Assessment System for Building Environmental Efficiency) in Japan (2004) and Green Star in Australia (2006). In Germany, which has always had a strong tradition of high-performance buildings, the German Green Building Council and the German government collaborated in 2009 to develop a building assessment system known as DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen), which is perhaps the most advanced evolution of building assessment systems. BREEAM, LEED, CASBEE, Green Star, and DGNB represent the cutting edge of today's high-performance green building assessment systems, both defining the concept of high performance and providing a scoring system to indicate the success of the project in meeting its sustainability objectives. In the United States, the green building movement is often considered to be the most successful of all the American environmental movements. The green building movement provides a model for other sectors of economic endeavor about how to create a consensus-based, market-driven approach that has rapid uptake, not to mention broad impact. This movement has become a force of its own and, as a result, is compelling professionals engaged in all phases of building design, construction, operation, financing, insurance, and public policy to fundamentally rethink the nature of the built environment. (Kibert 2016). This research conducted a screening of the world green building councils in order to record the current green building movement.

Table 2-3 contains a preliminary estimation of the common green building assessment tools around the world and the number of pursued projects. Table 2-4 outlines several of the most commonly used and respected green building rating and certification systems in the marketplace (Vierra 2016).

Table 2-3: The common green building assessment tools around the world

No	Country	Council	Rating System	Founded on	No. of Projects	Domain	Weather Zone
1	South Africa	Green Building Council South Africa	Green Star	2007	302	Global	BWh
2	Argentina	Argentina Green Building Council	LEED	2007	109	Global	BSk
3	Brazil	Brail Green Building Council	LEED	2007	1,221	Global	Af & As
4	Canada	Canada Green Building Council	LEED	2002	3,060	Global	Dfb & Dfc
5	Colombia	Colombia Green Building Council	LEED	2008	184	Global	Af & Am
6	Guatemala	Guatemala Green Building Council	LEED	2010	23	Global	Af
7	Panama	Panama Green Building Council	LEED	2009	73	Global	Af & As
8	Peru	Peru Green Building Council	LEED Edge BREEAM	2014	112	Global Global Global	Af & Cfb
9	United States of America	U.S. Green Building Council	LEED Living Building Challenge	1993	63,415	Global Global	Cfb & BSk
10	Australia	Green Building Council of Australia	Green Star	2003	1,461	Global	BWh
11	Hong Kong	Hong Kong Green Building Council	(BEAM)	2009	467	Local	BSh
12	India	Indian Green Building Council	IGBC based on LEED	2001	623	Local	BSh
13	Japan	Japan Sustainable Building Consortium	(CASBEE)	2001	541	Local	Cfb
14	Malaysia	Malaysia Green Building Confederation	Green Building Index	2007	116	Local	Af
15	Taiwan	Taiwan Green Building Council	N/A	2004	101 LEED	Local	Cfb & Cfc
16	Singapore	Singapore Green Building Council	For Product (SGBP) For Services (SGBS)	2009	68 LEED	Local	Af
17	New Zealand	New Zealand Green Building Council	**Green Star** for office and industrial buildings **Homestar** for housing **NABERSNZ** for office energy performance	2005	129	Local	Cfc
18	Philippines	Philippine Green Building Council	Building for Ecologically Responsive Design Excellence (BERDE)	2007	N/A	Local	Af & Am
19	Austria	ÖGNI – Austrian Sustainable Building Council	DGNB blueCARD	2009	134	Local	Cfb
20	Croatia	Croatia Green Building Council	LEED BREEAM DGNB	2009	4 LEED 1 BRE N/A	Global	Cfa
20	Finland	GBC Finland	LEED BREEAM	2010	170 LEED 26 BRE	Global	Dfb
21	France	Alliance HQE-GBC France	HQE	1996	48	Global	Cfb
22	Germany	German Sustainable Building Council	DGNB	2007	718	Global	Cfb

*N/A= Not Available

Table 2-4: The most used green building certification systems in the marketplace.

BUILDING RATING OR CERTIFICATION SYSTEM	SINGLE- OR MULTI-ATTRIBUTE	TYPE OF STANDARD OR CERTIFICATION	MANAGING ORGANIZATION	ISSUES / AREAS OF FOCUS
Energy Star	Single-Attribute	Government certification using a benchmarking method	U.S. EPA and U.S. DOE	Building energy and water use
Leadership in Energy and Environmental Design (LEED)	Multi-Attribute	Green building rating and certification system through independent third-party verification for: • New Construction (NC) • Existing Buildings, Operations & Maintenance (EB O&M) • Commercial Interiors (CI) • Core & Shell (CS) • Schools (SCH) • Retail • Healthcare (HC) • Homes • Neighborhood Development (ND)	U.S. Green Building Council	Performance in: • Sustainable Sites • Water Efficiency • Energy & Atmosphere • Materials & Resources • Indoor Environmental Quality • Locations & Linkages • Awareness & Education • Innovation in Design • Regional Priority through a set of prerequisites and credits
Green Globes	Multi-Attribute	Green building guidance and assessment program for: • Existing buildings • New construction	Green Building Initiative in the U.S. BOMA Canada	Environmental assessment areas to earn credits in: • Energy • Indoor Environment • Site • Water • Resources • Emissions • Project/Environmental Management • No prerequisites
Living Building Challenge	Multi-Attribute	• Performance-based standard, and certification program for: • Landscape and infrastructure projects • Partial renovations and complete building renewals • New building construction • Neighborhood, campus and community design	International Living Future Institute	Performance areas include: • Site • Water • Energy • Materials • Health • Equity • Beauty • All areas are requirements.
NZEB	Multi-Attribute	Certification program using the structure of the Living Building Challenge which can be applied to any building type.	International Living Future Institute	One hundred percent of the project's energy needs must be supplied by on-site renewable energy on a net annual basis, without the use of on-site combustion. NZEB certified buildings must also meet the following requirements of the Living Building Challenge: • the first half of Imperative One, Limits to Growth, dealing with appropriate siting of buildings • Imperative 19, Beauty and Spirit • Imperative 20, Inspiration and Education
Passive House Institute US	Multi-Attribute	• Performance based passive building standard • Third-party RESNET approved quality assurance/quality control • Earns U.S. DOE Zero Energy Ready Home status • Includes HERS rating	Passive House Institute US	Any type of building. New focus areas include: • air tightness requirement • source energy limit • space conditioning criteria
SITES	Multi-Attribute	Third party verified rating system for development projects located on sites with or without buildings.	Administered by GBCI	Performance criteria in the areas of: • Water • Wildlife Habitat • Energy • Air Quality • Human Health • Outdoor recreation opportunities
WELL Building Standard	Multi-Attribute	Performance based standard and certification program for • New and Existing Buildings • New and Existing Interiors	Administered by the International WELL Building Institute™ (IWBI)	Measures attributes of buildings that impact occupant health by looking at seven factors: Air, Water,

		• Core and Shell Retail • Education Facilities • Restaurant • Commercial Kitchen • Multifamily Residential		Nourishment, Light, Fitness, Comfort, Mind
INTERNATIONAL PROGRAMS				
BCA Green Mark Scheme **(Singapore)**	Multi-Attribute	Benchmarking scheme that aims to achieve a sustainable built environment by incorporating best practices in environmental design and construction, and the adoption of green building technologies.	Building and Construction Authority (BCA)	Rates buildings according to five key criteria: • Energy efficiency • Water efficiency • Environmental protection • Indoor environmental quality, • Other green and innovative features that contribute to better building performance.
Beam **(Hong Kong)**	Multi-Attribute	Comprehensive standard and supporting process covering all building types, including mixed use complexes, both new and existing to assess, improve, certify, and label the environmental performance of buildings	Business Environment Council	• Performance and assessment in: • Site aspects • Material aspects • Water use • Energy use • Indoor environmental quality • Innovations and additions
BREEAM **(UK, EU, EFTA member states, EU candidates, as well as the Persian Gulf)**	Multi-Attribute	Certification system is a multi-tiered process with pre-assessment, third-party consultant guidance through an assessment organization for: • New Construction • Communities • In Use Buildings and • EcoHomes	BRE Global	Assessment uses recognized measures of performance, which are set against established benchmarks in: • Energy and water use • Internal environment (health and well-being) • Pollution • Transport • Materials • Waste • Ecology and • Management processes
CASBEE **(Japan)**	Multi-Attribute	Building assessment tools for • Pre-design • New Construction • Existing Building and • Renovation	JSBC (Japan Sustainable Building Consortium) and its affiliated sub-committees	Assessment areas include: • Energy efficiency • Resource efficiency • Local environment, and • Indoor environment
EDGE	Multi-Attribute	A universal standard and a certification system for residential and commercial structures.	International Finance Corporation (IFC), a member of the World Bank Group	Assessment areas include: • Energy • Water • Materials
Green Star SA **(South Africa)**	Multi-Attribute	Green building rating system for: • Office • Retail • Multi-unit residential	Green Building Council of South Africa administers program Independent assessors to assess and score projects	Categories assessed in: • Management • Indoor Environmental Quality • Energy • Transport • Water • Materials • Land Use & Ecology • Emissions • Innovation
Pearl Rating System for Estidama **(UAE)**	Multi-Attribute	Green building rating system for: • Community • Buildings • Villas • Temporary Villas and Buildings	Abu Dhabi Urban Planning Council	Assessment of performance in: • Integrated Development Process • Natural Systems • Livable Communities • Precious Water • Resourceful Energy • Stewarding Materials • Innovating Practice

2.12 The Challenges of Adopting BIM and Green Building in MENA

The Middle East region, hindered by natural constraints and underlying political and social issues, has tried over the years to shift towards more sustainable practices in design and construction (Nivine Issa 2015). Governments in Middle Eastern countries have shown great efforts in the field of sustainability. They are creating their own rating systems that match its own community's social and natural environments needs, which is the most important step as the community is the targeted client with its cultural values that may raise the effectiveness of public role in design process. At last those rating systems started to gain more respect as it showed a solid base to be a reference guide for developing rating systems or encouraging other countries to have its own rating system that reflect the nature of each one, raising the importance of social aspects in MENA region (Iman Ibr. 2017). On the other hand, these efforts are hindered by natural and operational challenges that the region is forced to face. Some of the challenges faced are scarcity of water, lack of awareness in sustainability and environmental issues (despite the high education levels), and operational challenges such as retrofitting existing buildings (Nivine Issa 2015). In January 2018, German University in Cairo, a conference paper by Sara Khalifa and her team concluded the obstacles of fulfilling credits of GPRS in the Egyptian context as follows (S.Khalifa 2018):

- Absence of governmental incentives for redeveloping informal areas
- Absence of governmental incentives for following the national development plan
- Lack of specialist who are aware of environmental control strategies and building simulation programs to set the optimum alternative for the building environmental performance
- High initial cost

- Lack of qualified and awareness of contractors and builders
- Unavailability of data about life cycle cost of the available materials.
- Lack of using the required technology
- Unavailability of low emitting materials in the Egyptian market

2.13 Green Building councils in MENA area

A wide range of green building rating and assessment systems are used around the world. Sustainability is now a top priority in the Middle East and countries like Egypt, UAE, Lebanon, Qatar and other Arab countries have come up with their own green building rating system to incorporate the local environmental and cultural aspects in modern architecture.

2.13.1 Egyptian Green Pyramid rating System (EGPRS)

In January 2009, a major step was taken by establishing the Egyptian Green Building Council (EGBC). One of the objectives for establishing this council is to provide a mechanism to encourage building investors to adopt Building Energy Efficiency Codes (BEECs) as well as other sections of existing codes that satisfy both energy efficiency and environmental conservation. By focusing on new construction, the EGBC could use its leverage as a professional organization to educate and convince engineers, builders, contractors and owners about the benefits of green construction to the individual, to the community, to the nation and most significantly to the bottom line. In this manner, green construction would be the desired goal for all new building projects and building energy efficiency codes would be the materials, tools and road map to achieve the desired goal. As an immediate action to activate the role of this council, the developing a national Green Building Rating System called the Green Pyramid Rating System (GPRS). The council has commissioned to define the framework of a rating system and

a national committee has been formed to review and ultimately approve the Green Pyramid Rating System, which is completed in the first quarter of 2010, revised in the end of 2016, and the latest development was in 2018. Recognizing the unique ecological, industrial and social challenges of the region, the rating system helps to define what constitutes an "Egyptian Green Building". To accomplish that goal, the rating system supports the Egyptian BEECs and integrate proven methodologies and techniques used in successful programs from the United States, Europe, Asia, South America and the Middle East (EGBC 2018)

2.13.2 UAE Estidama - Pearl Rating System (PRS)

The Pearl Rating System (PRS) is the green building rating system for the emirate of Abu Dhabi designed to support sustainable development from design to construction to operational accountability of communities, buildings and villas. It provides guidance and requirements to rate potential performance of a project with respect to Estidama (or sustainability).The Pearl Rating System is an initiative of the part of the government to improve the life of people living in Abu Dhabi, by focusing on cultural traditions and social values. The rating system is specifically tailored to the hot and arid climate of Abu Dhabi which is characterized by high energy requirements for air-conditioning, high evaporation rates, infrequent rainfall and water scarcity. An essential tool to advance Estidama is the Pearl Rating System (PRS). The PRS is a framework for sustainable design, construction and operation of communities, buildings and villas. All new projects must achieve a minimum (1) Pearl rating to receive approval from the planning and permitting authorities. Government funded buildings (as defined in Information Bulletin #1) must achieve a minimum (2) Pearl rating (DPM 2018)

2.13.3 Lebanon ARZ Building Rating System

ARZ Building Rating System is the first Lebanese green building initiative of international standard with its certification process being administered by the Lebanon Green Building Council (LGBC). The ARZ Building Rating System is designed to measure the extent to which existing commercial buildings in Lebanon are healthy, comfortable places for working, consuming the right amount of energy and water, while having a low impact upon the natural environment. In addition, the rating system will stimulate building owners and facility managers to achieve ever-higher certification levels to attract discerning tenants and clients (LGBC 2018)

2.13.4 Saudi Arabia - saaf® Green Building

The saaf® certification, an application (online based) for general registration (unverified), verification (existing certification) and certification (a reading system) comply with ISO/IEC 17065 requirements for bodies certifying (Products, Processes, and Services), under-accreditation by the International Accreditation Service (IAS), saaf® is a registered trademark of Ministry of Commerce and Industry, Saudi Arabia. saaf® certification may include process as a scientific and technical services, research, registration of documentation to be achieved by professionals and products/ services of construction materials for buildings and their applications design and implementation, operation and removal. saaf® certification process is using in one of the following areas 1 / People 2 / Products and Services 3 / Projects to take advantage of the documentation for the security and safety and human health and the environment for the benefit of (individuals or institutions) who are authorized to carry a label saaf® (SGBF 2017)

2.14 Criteria for Green Building Rating Systems

The U.S. General Services Administration (GSA) identified seven-review criteria in order to evaluate sustainable building rating systems. The following screening criteria used to focus the review on a set of potentially applicable sustainable building rating systems Table 2-5 shows the criteria and sub-criteria of sustainable building rating systems:

- **Applicability**: For a rating system to address Executive Order 13123 guidance, the Energy Policy Act of 2005 and the GSA goals, it needs to be usable on all of its project and building types.
- **Development**: for the rating system to be aligned with the Memorandum of Understanding, the use of life cycle concepts, consensus-based standards, and performance measurement is encouraged.
- **Usability**: for the rating system to be applied effectively for all of the GSA building types and projects, it needs to be relatively simple and practical to use.
- **System Maturity**: for the rating system to address the GSA goal of being a trusted advisor on sustainable design projects, the system needs to be dependable, have a proven track record, and be endorsed by respected organizations.
- **Technical Content**: for the rating system to address the Memorandum of Understanding, the Energy Policy Act, and Executive Order 13101, the system needs to address the primary areas of sustainable design – siting, energy use, water use, indoor environmental quality, and materials selection.
- **Measurability & Verification**: for the rating system to address the Energy Policy Act guidance to comply with third party certification standards and the GSA goal for assisting with performance metrics, the

system needs to have a standardized, verifiable system for documenting sustainable design related performance.

- **Communicability:** for the rating system to address the GSA goal of being able to communicate their sustainable design approaches for creating world class workplaces in a corporate reporting style, the results needs to be versatile across building and project types, well-known by outside organizations, and easy to understand.

These criteria also contribute to the credibility of the rating system. It is critical to understand the basis of the rating systems in order to explain it to others and ensure the sustainable design environmental performance goals are being met when desired ratings are achieved.

Table 2-5: Criteria of Green Building Rating Systems

Criteria	Sub-Criteria
Applicability	Type of Projects Type of Buildings
Development	System Management Development Approach Openness of Operations Transparency of Rating System
Usability	Cost Ease of Use Product support
System Maturity	System Age Number of Buildings Stability of system
Technical Content	Relevance to Sustainability Thoroughness Measurement comparison
Measurability & Verification	Standardization Quantification Certification/Verification Process Documentation Verifiable/Defendable
Communicability	Clarity Versatility Comparability Results Usability:

2.15 The International Green Construction Code (IgCC®)

Code officials recognize the need for a modern, up-to-date code governing the impact of buildings and structures on the environment. The International Green Construction Code® (IgCC®) is designed to meet this need through model code regulations that contain clear and specific requirements with provisions that promote safe and sustainable construction in an integrated fashion with the ICC Family of Codes (International Code Council 2018). This comprehensive green code establishes minimum regulations for building systems and site considerations using prescriptive and performance-related provisions. It is intended to be an overlay code to be used, and is fully compatible with all of the International Codes® (I-Codes®). Its published by the International Code Council (ICC) ®, including the International Building Code®, International Energy Conservation Code®, International Existing Building Code®, International Fire Code®, International Fuel Gas Code®, International Mechanical Code®, ICC Performance Code®, International Plumbing Code®, International Private Sewage Disposal Code®, International Property Maintenance Code®, International Residential Code®, International Swimming Pool and Spa Code®, International Wildland-Urban Interface Code® and International Zoning Code®. The International Green Construction Code® provisions provide many benefits, among which is the model code development process that offers an international forum for building professionals to discuss performance and prescriptive code requirements. This forum provides an excellent arena to debate proposed revisions. This model code also encourages international consistency in the application of provisions. This code has been developed in collaboration with the following Cooperating Sponsors: The American Institute of Architects (AIA); ASTM International; ASHRAE; the U.S. Green Building Council (USGBC); and the

Illuminating Engineering Society (IES). ICC wishes to thank these Cooperating Sponsors for recognizing the need for the development of a comprehensive set of green regulations that are enforceable, usable and adoptable. (International code council 2015)

2.15.1 Benefits of the IgCC

- The IgCC® provides a whole systems approach to the design, construction and operation of buildings.
- The International Green Construction Code includes measures that result in better indoor environments, lower impact on natural resources, better neighborhood connections, & improved walkability.
- The IgCC® is coordinated with other model codes such as IECC®, 90.1, and many other referenced standards.
- The IgCC® is a public/private collaboration that provides a green model code to government jurisdictions. As a result, government does not have to take on the high cost of developing its own code and benefits from the code uniformity among adopting jurisdictions.
- USGBC is developing synergies between specific IgCC® measures and LEED® credits, enabling a streamlined approach to leadership that is built on a consistent green code. (International Code Council 2018).

2.15.2 IgCC® Development

The IgCC® provisions provide many benefits, among which is the model code development process that offers an international forum for building professionals to discuss performance and prescriptive code requirements. This forum provides an excellent arena to debate proposed revisions. This model code also encourages international consistency in the application of

provisions. The 2018 IgCC® is expected to be available mid-2018. The available current version is: 2015 IgCC®. (International Code Council 2018).

2.16 LEED® Green Building Program

USGBC's Leadership in Energy and Environmental Design (LEED) is a third-party green building certification program and an international symbol of excellence in the design, construction, and operation of high-performance green buildings and neighborhoods. It encourages and accelerates adoption of sustainable building and community development practices through the creation and implementation of a green building benchmark that is voluntary, consensus based, and market driven (Erdman 2014).

2.16.1 LEED® Development and history

LEED was developed by USGBC, and the LEED Green Building Rating System is the USGBC's primary vehicle for promoting sustainable design and construction. The LEED standard was created through volunteer committees. From 1994 to 2013, LEED grew from one standard for new construction to a comprehensive system of interrelated standards covering all aspects of the development and construction process. LEED also has grown from six volunteers on one committee to more than 200 volunteers on nearly 20 committees and nearly 150 professional staff (GBES 2014). At the beginning, Rick Fedrizzi, David Gottfried and Mike Italiano established USGBC in 1993 with a mission to promote sustainability-focused practices in the building industry. Representatives from around 60 firms and several nonprofits gathered that April in the American Institute of Architects' boardroom for the founding meeting. It was then that ideas were shared for an open and balanced coalition spanning the entire building industry and for a green building rating system, which would later become LEED. Since the rating system's unveiling

in 2000, it has become an international standard for environmentally sound buildings, certifying hundreds of thousands of square feet per day (USGBC 2018). While LEED v1 was a great starting point, Watson found much of the criteria was either too narrow or already standard practice and did not sufficiently measure energy performance. In March 2000, LEED v2 was approved with an expansion from 40 to 69 credits and four certification achievements. The most commonly used version of LEED, LEED v3, was launched in 2007 with the ability to earn up to 110 points. The next update for LEED v3 was completed in 2009 (v2009). The current version is LEED v4 was approved in July 2013 and launched in November 2013. LEED v4 incorporates technology and government policies and standards that have evolved over the years, as well as stricter requirements for the improvement in carbon reduction and human health day (USGBC 2018).

2.16.2LEED® Impact Categories and Goals

As a market transformation instrument, LEED engages building project teams in a way that connects strategies to a defined set of goals. LEED's system goals are referred to as "Impact Categories." Seven Impact Categories were developed and approved by the LEED Steering Committee for incorporation into LEED v4. These Impact Categories answer the question: "What should a LEED project accomplish?" (Owens 2014). Figure 2-9 illustrates weighting of the LEED v4 Impact Categories to account for differences in scale, scope, severity and relative contribution of the built environment to the impact

- Reverse Contribution to Global Climate Change
- Enhance Individual Human Health and Well Being
- Protect and Restore Water Resources

- Protect, Enhance and Restore Biodiversity and Ecosystem Services
- Promote Sustainable and Regenerative Material Resources Cycles
- Build a Greener Economy
- Enhance Social Equity, Environmental Justice, and Community Quality of Life

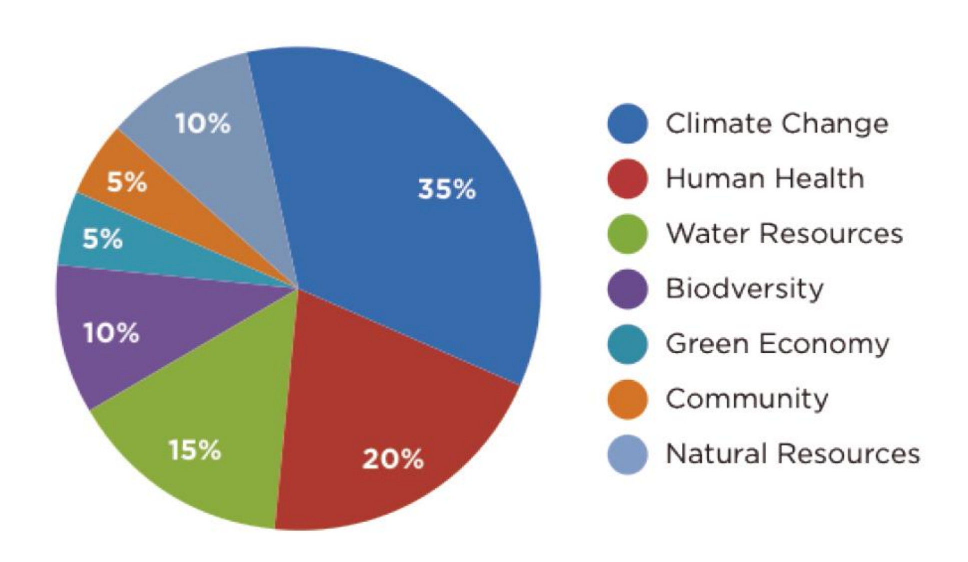


Figure 2-9: Weighting of the LEED v4 Impact Categories

2.16.3 LEED® Certification Levels

The LEED v4 green building certification system is a voluntary and consensus-driven process for quantifying the impact of the built environment and construction activities across several impact categories. The categories address globally significant environmental, social, health, and economic issues and provide performance metrics as well as best practices and processes for improving buildings in these areas (GSA 2014). Even though there have been different versions throughout the years, the basis of LEED is a point system where building projects are required to fulfill all prerequisites and minimum program requirements, while LEED credits are optional. Project teams must pursue a minimum of 40 LEED points with any combination of

credits of their choosing. There are four different certification levels: Certified, Silver, Gold, and Platinum Table 2-6 shows the LEED v4 certification levels and points. Although still a part of the USGBC, as of 2008 LEED project certifications are administered through Fedrizzi's sister organization Green Business Certification, Inc (GBCI).

Table 2-6: LEED v4 Certification Levels

Certification Level	Points
Certified	≥ 40 < 50
Silver	≥ 50 < 60
Gold	≥ 60 < 80
Platinum	≥ 80

2.16.4 LEED Rating Systems

In order to receive LEED certification, building projects must satisfy prerequisites and earn points to achieve different levels of certification. Each rating system groups requirements that address the unique needs of building and project types on their path towards LEED certification. Once a project team chooses a rating system, they will use the appropriate credits to guide design and operational decisions. Four primary LEED rating system groups cover 21 LEED rating systems, five LEED reference guides, and five LEED Accredited Professional (AP) specialty exams and credentials. Table 2-7 summaries LEED rating system groups and guide references (GBES 2014).

Table 2-7: LEED Rating System Groups and references

LEED Rating System Groups	LEED Rating Systems	LEED Reference Guides	LEED Exams/Credentials
LEED for Building Design and Construction	LEED BD+C: New Construction LEED BD+C: Core and Shell LEED BD+C: Schools LEED BD+C: Retail LEED BD+C: Healthcare LEED BD+C: Data Centers LEED BD+C: Hospitality LEED BD+C: Warehouses and Distribution Centers	LEED Reference Guide for Building Design and Construction	LEED AP BD+C
	LEED BD+C: Homes LEED BD+C: Multifamily Midrise	LEED Reference Guide for Homes Design and Construction	LEED AP Homes
LEED for Interior Design and Construction	LEED ID+C: Commercial Interiors LEED ID+C: Retail LEED ID+C: Hospitality	LEED Reference Guide for Interior Design and Construction	LEED AP ID+C
LEED for Building Operations and Maintenance	LEED O+M: Existing Buildings LEED O+M: Data Centers LEED O+M: Warehouses and Distribution Centers LEED O+M: Hospitality LEED O+M: Schools LEED O+M: Retail	LEED Reference Guide for Building Operations and Maintenance	LEED AP O+M
LEED for Neighborhood Development	LEED ND: Plan LEED ND: Built Project	LEED Reference Guide for Neighborhood Development	LEED AP ND

2.16.5 LEED® Rating System Structure

LEED® v4 can be applied to any building at any point in the building's lifecycle. In order to measure if a building has met the definition of a high performance green building as defined by LEED®, every LEED® rating system (except LEED for Neighborhood Development) has performance criteria in these major areas (GBES 2014):

- Location and Transportation – does the location preserve environmentally sensitive places and take advantage of existing infrastructure, community resources, and public transit.
- Sustainable Sites – is the selected site able to maximize sustainability?
- Water Efficiency – what can you do to save on landscaping water use and interior water use?
- Energy and Atmosphere – how can you save energy, cut energy costs and encourage green energy development and use?
- Materials and Resources – are your building materials sustainable for the environment, and where does the waste go?
- Indoor Environmental Quality – how can you increase the productivity, satisfaction, and health of the occupants?
- Innovation – what can you discover that isn't in the rating system to add even further value to the project?
- Regional Priority – Are there regionally important issues such as water conservation in the Southwest?

CHAPTER 3

Building Information Modeling – BIM

The National Building Information Model Standard Project Committee defines BIM as: "Building Information Modeling (BIM) is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition." A basic premise of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder. The promote of BIM and BIM interchanges requirements are based on:

- a shared digital representation,
- that the information contained in the model be interoperable (i.e.: allow computer to computer exchanges),
- and the exchange be based on open standards,
- The requirements for exchange must be capable of defining in contract language.

As a practical matter, BIM represents many things depending on one's perspective:

- Applied to a project, BIM represents Information management-data contributed to and shared by all project participants. The right information to the right person at the right time.
- To project participants, BIM represents an interoperable process for project delivery-defining how individual teams work and how many teams work together to conceive, design, build & operate a facility.

- To the design team, BIM represents integrated design-leveraging technology solutions, encouraging creativity, providing more feedback, empowering a team (National BIM Standards 2018).

3.1 The Importance of BIM

Buildings cost more than they should to design, build and sustain and they take too long to deliver. We must do a better job of collaborating between the many stakeholders involved in the building process. In a recent National Institute of Standards and Technology-NIST study lack of interoperability was identified as an additional cost to the owner of $15.8B annually but most in the industry feel that this number is significantly higher as the business opportunity of improved interoperability was not included. This aspect of our business can be improved greatly with better information management and business process re-engineering to create standard information exchanges between the stakeholders. This improved business model will not detract from the creative nature of facility design, but in fact profoundly improve the customer experience. There are some immediate actions we must take in order to change:

- Improve collaboration between information suppliers and users in the facility business
- Provide more accurate fundamental information to support decision making
- Provide a standard way of storing information so that it survives the test of time

Build data collection and sustainment of information into our business processes. The fragmented nature of our industry is a legacy of atelier and, later trade union practices which were eventually codified in legal and ethical separations between owners, designers, constructors, vendors and end-users.

Even when parties to the building process began using CAD technology many years ago, business practices were still compartmentalized and the underlying communications medium was still graphical abstractions of real objects represented in drawings and specifications produced on printed media. BIM is the evolutionary business transformation step needed to reform the capital facilities industry. Using BIM principles and practices, elements of the capital facilities industry are represented and exchanged digitally. Digital representation means that computers can be used to 'build' the capital facility project virtually, view and test it, revise it as necessary, and then output various reports and views for purchasing, fabrication, assembly, and operations. In many cases paper output may be avoided altogether when the finalized digital designs are sent directly to procurement systems and/or digital fabrication equipment. (National BIM Standards 2018). In 2011, Salman Azhar stated that, building information modeling (BIM) is one of the most promising recent developments in the architecture, engineering, and construction (AEC) industry. With BIM technology, an accurate virtual model of a building is digitally constructed. This model, known as a building information model, can be used for planning, design, construction, and operation of the facility. It helps architects, engineers, and constructors visualize what is to be built in a simulated environment to identify any potential design, construction, or operational issues. BIM represents a new paradigm within AEC, one that encourages integration of the roles of all stakeholders on a project. (Azhar 2011)

The use of building information modeling (BIM) has provided a means of increasing total project quality, providing accurate quantity take-offs, and improving scheduling, consequently diminishing total project contingencies and costs. Although BIM is a recent development, a lot of research has been

conducted in order to further enhance the capabilities of BIM in design and construction (Patrick Bynum 2013).

3.2 The Fundamentals of a BIM Approach.

Building information modeling is an integrated model-centric methodology that delivers validated and coordinated knowledge about a building project throughout planning, design, construction, and operation. When this collaborative, interdisciplinary approach is optimized, it can improve an organization's operations. BIM provides designers, contractors, and owners with a process to improve decision-making, quality, and timeliness. At the core of this BIM approach are model-centric workflows (geometric and data models) that support project execution and asset lifecycle management. These workflows determine the methodology for creating data-rich geometries, integrated deliverables, and a model-based process to develop projects from planning through the operation and management lifecycle phases. BIM can be defined through technology, processes (its governance through standardization), and people. The technology system is central to the processes of creating, storing, and using models. With processes, the success of BIM requires all stakeholders in the project ecosystem to follow a series of steps, both as individuals and as a team. Ultimately, the users of these techniques and technologies are committed to improving their design process by successfully integrating both geometry and data. To succeed with these practices in this environment, a business must make fundamental changes in the way it operates, whether by moving into a new market or by changing its methods of operation. It requires an alignment of the organization's activities relating to its people, processes, and technology with its business strategy and vision. Through collaboration and data management during an asset's lifecycle, sharing information efficiently and effectively can support better

integration and interoperability among all project stakeholders. Along with this data comes the possibility of integrated analysis. By making these analyses easily accessible, derivatives of this model-centric workflow can provide a better understanding of design opportunities and decisions' consequences. With the availability of valid geometry-based data, 2D, 3D (visualization, clash detection), 4D (time), 5D (cost), and beyond are possible. Taking advantage of these capabilities is a must in keeping architecture relevant in today's market (Lance Kirby 2018).

3.3 Benefits, limitations, obstacles and problems of BIM

Years ago, Patrick MacLeamy, who was then CEO of Hellmuth, Obata, + Kassabaum, explained this workflow movement with a diagrammatical description of the shift of workload and the ease of affecting change in the construction process forward. The graph, which has come to be known as the MacLeamy curve (Figure 3-1), is not simply intended to imply a shift in labor earlier in the design process; rather, it stresses the importance of being able to make higher-value decisions earlier before changes become too difficult or costly to implement. The x-axis of the chart represents project phases from conceptual design through occupancy, whereas the y-axis represents the amount of effort in each phase (Lance Kirby 2018). In 2013, Darius Migilinskas and his team from Vilnius Gediminas Technical University, concluded that; "The information and data collected in four cases studied in their research, enabled the team to determine productivity and profitability gains as well as learn experience of the BIM implementation team. The experience of project participants as the team allowed as to define process of the decision making before start of the BIM implementation in separate projects as well as to make recommendation about BIM process planning in

the environment of small companies with different software and methodologies of works.

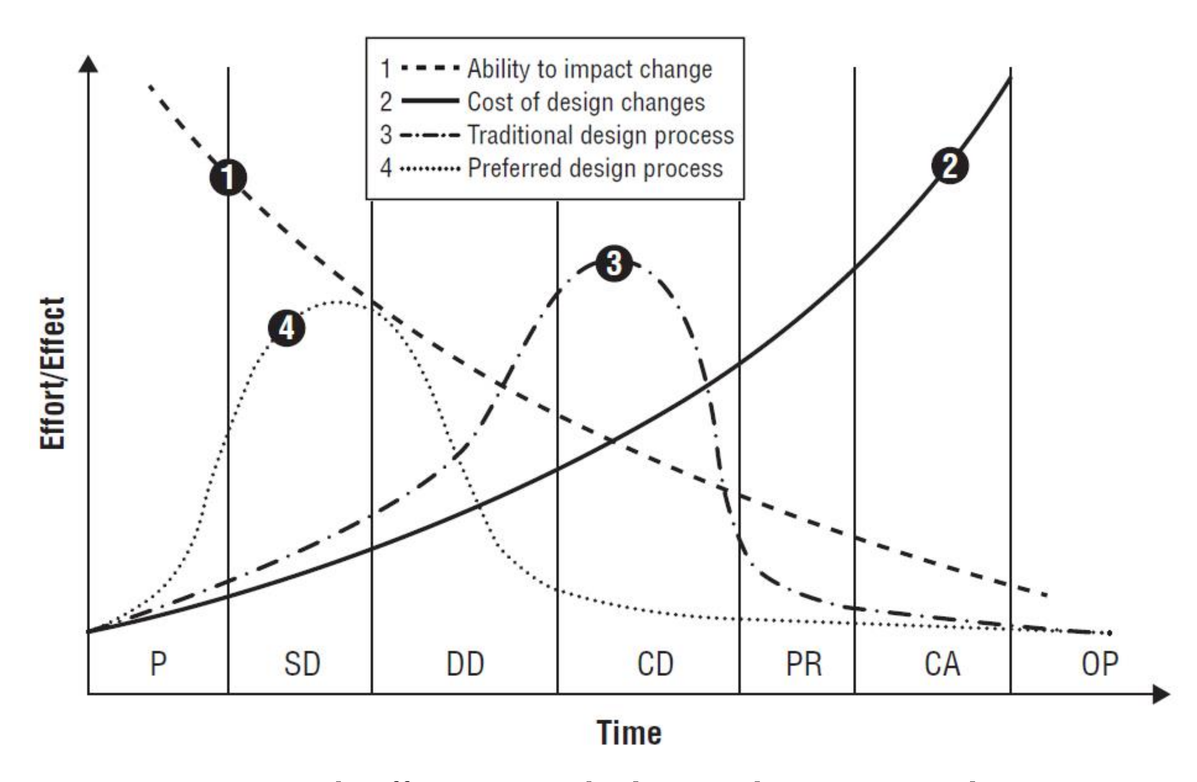


Figure 3-1: The effort curves in the design and construction industry

The BIM implementation requires urgent development of the reliable tools for information exchange between different software tools at same time enabling efficient and direct coordination and monitoring processes between project participants and team members, employed for the project from different companies and using various tools as software sets. For more acceptable BIM implementation, the acceptable level of interoperability and standardizing the work methods must be prepared for project participants and team members. The BIM technology and tools are developing rapidly (based on basic BIM methodology), but their effective and fast use in the practice are constrained by existing contractual arrangements and traditional organization in the projects directed by stronger party with atmosphere of fights for individual

benefits instead for search better project delivery solutions and alternatives, which can make participation in the project delivery beneficial for all involved. (Darius Migilinskasa 2013).

AECOM report 28th edition©, (AECOM 2017) concluded that the possible benefits of BIM from a cost management perspective:

- Fast, reliable and accurate quantity take-off and cost estimation.
- Auto computation of calculations, hence reduced calculation mistakes.
- Categorized cost reporting and estimation via the use of zones/locations.
- Improved visualization of the elements for measurement and costing purposes.
- Easy project handover between quantity surveyors.
- Enhanced communication and collaboration amongst team.
- Improved cost database management.
- Facilitated change management.
- Enables a more proactive outlook from a quantity surveying perspective with regard to cost management, contract management and cost engineering.

3.4 BIM Status Globally

BIM is mandated in some countries such as US, UK and a number of other countries as per the Smart Market Report. In USA, the BIM adoption has increased by 54 % between the 2007 and 2012. In 2010, BIM adoption in European countries reached 36%. In the UK, BIM adoption between 2010 and 2012 increased from 13% to 39%, respectively. In the Middle East, only 10% of construction projects are using BIM. Some countries in the Europe such as Finland, Denmark. Norway and Sweden are known as the BIM leaders in the word. Accordingly, there are numerous publications, research results, and

policies developed for BIM implementation in Europe. In the UK there’s a high level of BIM awareness among construction professionals. The BIM awareness might be relied on the UK government and its fund and support for the AEC industry. The BIM adoption is mandated by the UK government to be used in 2016 to level 2 for all public governmental construction projects by 2016 for the purpose of reducing construction waste by 20%. In the USA, BIM is used for visualization purposes in almost 70% of construction projects. In addition, most of the projects use BIM for the design stage of projects. In Singapore, the BIM e-submission was mandated by the government in 2008 through the two organizations of Building and Construction Authority (BCA) and the Construction and Real Estate Network (CORENET). Singapore is the earliest BIM adaptor in Asia, and the first in the world to require the BIM submission. A BIM Draft handbook was produced in 2014 to be used as a guide and a supporting document to help in the BIM implementation to be used in the New Zealand and Australian AEC industry. That document was introducing as "BIM as a changer” (Mehran 2016).

McGraw Hill SmartMarket report 2017 analyzed a survey data collected exclusively from construction companies that use BIM in nine of the world’s top construction markets to improve productivity, efficiency, quality, safety and their own competitiveness. Among the key findings:

- Three quarters of the construction companies report a positive Return on Investment (ROI) on their BIM program investment and have clear ideas about how to further improve ROI.
- Fewer errors and omissions less rework and lower construction costs are among the top five BIM benefits cited by contractors.
- Over the next two years, contractors expect the percentage of their work that involves BIM will increase by 50% on average.

- BIM ROI increases directly with a contractor's level of BIM engagement, represented by its BIM experience, skill level and commitment to doing a high percentage of its work in BIM.
- Contractors in all markets are planning significant investments to expand their BIM programs over the next two years, including an increasing focus on internal and external collaborative procedures as well as mobile hardware and BIM software (McGrawHill 2017).

3.5 Building Energy Modeling Software Tools

The past decade has seen remarkable growth in the Building Energy Modeling industry, primarily driven by more stringent building energy efficiency standards and a growth in voluntary building energy certification programs such as LEED. Following are descriptions of the most widely used Building Energy Modeling (BEM) tools in the United States, both calculation engines and interfaces, at the time of writing of this guide. While extensive, this list makes no claim to being comprehensive. Please note that these tools are currently and typically used later in the design process, once engineering system selection has occurred, and for code or third party rating/certification compliance. The energy modeling simulation and program development industry is gaining widespread adoption at an increasingly rapid rate; thus, new whole building modeling tools, as well as associated Design Performance Modeling, tools are being developed and released regularly. It may be worth noting that the holy grail of energy modeling software has yet to be found. Architects and software developers are still on this quest, and all tools have pros and cons. What is important is to pick one that seems appropriate for your practice and that you are comfortable with and to simply start using it. Table 3-1 shows the energy simulation tools developers.

Table 3-1: Energy Simulation Tools Developers (AIA 2012)

Engine	Interface	Publicly & funded	Free
DOE-2	eQUEST	yes	**yes**
	Visual DOE	yes	**yes**
	EnergyPro		
	Autodesk GBS		
EnergyPlus	Bentley Hevacomp		
	Design Builder		
	OpenStudio	yes	**yes**
	Simergy	yes	**yes**
Energy 10		yes	**yes**
TRNSYS	TRNSYS	yes	**yes**
HAP	HAP		
IES-VE	IES-VE		
TRACE 700	0 TRACE 700		

3.6 Screening the Building Energy Engines/Tools

3.6.1 EnergyPro

EnergyPro is an interface for the DOE-2.1E engine that can be used to perform several different whole-building energy modeling calculations, most widely used for California code compliance: California Title 24 hourly energy analysis of low-rise residential buildings with an approved residential simulation (ResSim*); or California Title 24 energy analysis of nonresidential

Table 3-2: Currently Available Building Energy Modeling Software Tools (AIA 2012)

buildings, hotels/motels and high-rise residential buildings with either a prescriptive method approach (NR Prescriptive*), or a performance simulation method (Win/DOE*). Note: (title*) indicates the name of the specific package that should be used for the associated project type or compliance path (AIA 2012).

Table 3-2 The Available Building Energy Modeling Software Tools (AIA 2012)

Modeling Tool	Calculation Engine	Graphic interface for front-end input	Graphic results provided	Appropriate for early design phase	Approved for code compliance modeling	Free ware
COMFEN (RESFEN – residential)	EnergyPlus	yes	yes	yes	No	yes
DesignBuilder	EnergyPlus	yes	Limited	yes	yes	No
Ecotect	CIBSEAdmittance Method	yes	yes	yes	No	No
EMIT1.2	None (spread-sheet)	No	Not specifically, but s/s	yes	No	yes
Energypro	DOE-2.1E	No	No (auto-generates compliance report)	No	Yes (easiest to use)	No
eQUEST®	DOE-2.2	yes	No	Mustbefar enough alongto inputHVAC	yes (most popular)	yes
green building studio / Vasari	DOE-2.2	yes	yes	yes	No	No
hourly Analysis program (HAP)	Transfer Function Method	Limited	No	No	yes	No
IES virtual Environment	Apache	yes	yes	Gaia +Toolkit yes Pro requires input of	yes	No
OpenStudio	EnergyPlus	yes (similar to SketchUp)	yes	Must befar enou	yes	yes
Sefaira concept	Sefaira	yes	yes	yes	No	No
Simergy	EnergyPlus	yes	Limited	Not yet	yes	yes
TAS	TAS	yes	yes	yes	yes	No
TRACE® 700	TRACE	No	Limited	Must befar enou	yes	No
TRNSYS	TRNSyS	yes	No	No	No	No

3.6.2 VisualDOE™

Is a Windows interface for the DOE-2.1E energy simulation engine, through which users can construct a model of the building's geometry using standard block shapes, a built-in drawing tool, or by importing DXF files. It is arguably friendlier and easier to use than eQUEST. Building systems are defined through a point-andclick interface. A library of constructions, fenestrations, systems, and operating schedules is included, from which the user can choose, although the user can add customized elements as well (AIA 2012).

3.6.3 DOE-2 (engine)

DOE-2 is a Building Energy Modeling program developed by Lawrence Berkeley National Laboratory, funded by the Department of Energy. It calculates energy performance and life-cycle costs of operation of whole-building projects. Two versions exist: DOE-2.1E and DOE-2.2.

3.6.4 Green Building Studio (GBS)

GBS links Autodesk architectural building information models (BIM) and certain 3D CAD building designs with energy, water, and carbon analysis, enabling architects to quickly receive feedback about the operational and energy implications of early design decisions. The Autodesk GBS web service automatically generates geometrically accurate, detailed input files for major energy simulation programs. GBS uses the DOE-2.2 simulation engine to calculate energy performance and creates geometrically accurate input files for EnergyPlus (AIA 2012).

3.6.5 eQUEST®

Is probably the most widely used graphic interface for the DOE-2.2 calculation engine. Its wizards, dynamic defaults, interactive graphics, parametric analysis, and rapid execution make eQUEST able to conduct

whole-building performance simulation analysis throughout the entire design process, from the earliest conceptual stages to the final stages of design (AIA 2012).

3.6.6 EnergyPlus (engine)

EnergyPlus is DOE's flagship Building Energy Modeling tool. Replacing the DOE-2 engine, EnergyPlus provides more accuracy, fewer workarounds, and enables the analysis of more innovative and complex mechanical system and building designs. DOE has been funding on-going improvements to the analysis capabilities of this powerful engine to increase its application for existing buildings and low-energy designs, as well as new-construction, conventional buildings. While, to date, EnergyPlus has been used primarily by researchers, an increasing number of programs are linking and developing interfaces to the EnergyPlus engine to provide users with the capability to analyze natural ventilation, ground source heat pumps, and radiant systems within their overall building designs (AIA 2012).

3.6.7 Hourly Analysis Program (HAP)

Carrier's Hourly Analysis Program (HAP) is a versatile system design tool and an energy simulation tool in one package, with a Windows-based graphical user interface. HAP's design module uses a system-based approach to HVAC load estimating. This approach tailors sizing procedures and results to the specific type of system being considered. Calculation rigor and integrity are provided by the ASHRAE Transfer Function Method for calculating building heat flow (AIA 2012).

3.6.8 TRaNsient SYstem Simulation Program (TRNSYS)

TRNSYS Is a commercially-available, i.e., not free, Building Energy Modeling program whose modular system approach makes it one of the most

flexible tools available. TRNSYS includes a graphical interface, a simulation engine, and a library of components that range from various building models to standard HVAC equipment to renewable energy and emerging technologies. TRNSYS also includes a method for creating new components that do not exist in the standard package. This simulation package has been used for HVAC analysis and sizing, multizone airflow analyses, electric power simulation, solar design, building thermal performance, analysis of control schemes, etc. (AIA 2012).

3.6.9 DesignBuilder™

DesignBuilder provides a user-friendly modeling environment, accommodating a range of environmental performance data, such as energy consumption, internal comfort data, and HVAC component sizes. Output is based on detailed sub-hourly simulation time steps (AIA 2012).

3.6.10 OpenStudio

Developed by the National Renewable Energy Laboratory, OpenStudio is an interface that provides users easy access to a number of building analysis engines. OpenStudio's reputation is in providing easier access to the energy analysis engine EnergyPlus, and increasingly, interfaces with other performance analyses engines such as Radiance for lighting, CONTAM for airflow and air quality simulation. It is including a SketchUp-type modeling capability that allows users to 'build'/specify geometry, space types, and thermal and lighting zones in a 3D modeling construct, similar to architectural 3D modeling programs (rather than the extruded floor-plan constructs of most energy modeling graphic interfaces). It gives users access to editing building schedules, constructions, internal loads, and mechanical systems, with an

intuitive, drag-and-drop interface and includes basic visualization modules for viewing simulation results in more intuitive formats (AIA 2012).

3.6.11 Simergy

Simergy is the newly developed graphic interface for EnergyPlus, affording more user-types the ability to analyze design performance at different stages in the design process. In addition to analyzing alternatives related to building form, glazing percentage/type, exterior shading, and aspects of daylighting at early stages of design, Simergy also allows high performance HVAC systems to be effectively included. A comprehensive set of templates and libraries for ASHRAE 90.1, LEED, California Title 24, and low energy HVAC systems allow the user to incorporate innovative HVAC systems, such as chilled beams with displacement ventilation, into the building energy model without questionable work-arounds (AIA 2012).

3.6.12 IES® Virtual Environment

IES is an integrated suite of tools designed to allow building performance analysis to be easily integrated into commercial workflows across the entire design lifecycle. The APACHE engine is the core energy simulation component in all four of the Virtual Environment tiers (backed up by other engines for related performance analysis, such as Radiance for daylighting). In design mode, APACHE covers the calculation of heating, cooling, and latent room loads, the sizing of room units, internal comfort analysis, and codes/standards checks. In simulation mode, APACHE can operate at time-steps as small as one minute and performs a dynamic thermal simulation using hourly weather data. Integrated components of APACHE permit simultaneous simulation of HVAC plant, solar gains and shading, natural ventilation, and dimming strategies (AIA 2012).

3.6.13 TRACE® 700

Trane Air Conditioning Economics, or TRACE, is a design and analysis tool developed to help professionals optimize the design of a building's heating, ventilating, and air-conditioning system based on energy utilization and life-cycle cost. It is a complete load, system, energy, and economic analysis program that compares the energy and economic impact of building alternatives, such as architectural features, HVAC systems, building utilization, or scheduling and economic options. Users can choose from a large variety of systems, economizers, and plant configurations, including water-source and central or distributed ground-source systems, underfloor air distribution systems, dedicated outdoor-air systems, and optimized control strategies. TRACE 700 includes ASHRAE Standard 90.1 equipment and envelope libraries, gbXML imports, weather files, templates, Building Information Modeling, and more. TRACE 700 complies with Performance Rating Method of ASHRAE Standard 90.1-2007 for LEED analysis, and was the first simulation software approved by the IRS for energy-savings certification (AIA 2012).

3.6.14Energy-10 (engine)

Energy-10 is a Design Performance Modeling tool focused on making tradeoffs during early design phases for buildings that are less than 10,000 sf floor area, or buildings that can be treated as one- or two zone increments. Performs whole-building energy analysis for 8760 hours/year, including dynamic thermal and daylighting calculations. Specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of design (AIA 2012).

CHAPTER 4

Literature Review

Studies on the integration of BIM in to Green Building analysis have been conducted to find out the experiences of the application of BIM in Green Building analyses. Krygiel et al. summarized several case studies with successful implementation of BIM in LEED® and other green projects. In his study, an in-depth analysis of BIM application was conducted in various building systems including building envelopes, water harvesting, energy modeling, renewable energy and sustainable materials. However, site location was not a subject of BIM application in his study (Eddy Krygiel 2008). The Architectural, Engineering, Construction & Operation (AECO) industry has witnessed assured development through BIM implementation in parallel with constant drive of green building movement in the last two decades. Although the two concepts are independent of each other, BIM and green building collectively are able to overcome present challenges in productivity and, assessment tools help industry stakeholders evaluate the performance of green buildings (Amarnath-CB 2016). BIM enables architecture, engineering, and construction managers to evaluate the performance of green buildings during preconstruction. BIM-based sustainable analysis extracts the data from a building model, which supports the assessment for green building certification. (Moh.-Solla 2016). Green building rating systems, which feature their respective criteria and allocation of points and credits; thus, BIM may possibly be integrated with the green building certification process. This factor is a strong reason driving several countries to implement BIM in most construction phases. (W. A. Salman Azhar 2011). The BIM model assists project stakeholders, including designers, contractors and clients, in

calculating, documenting, and measuring the green building rating system scores based on the LEED, BEAM Plus, and Green Star certification. In the future, the design team and construction approaches should meet the LEED, BEAM Plus, and Green Star rating systems for green building accreditation requirements (W. A. Salman Azhar 2011).

4.1 Leveraging BIM in sustainable building

The emergence of BIM as a design and visualization tool is an important trend for the building industry. Its three-dimensional modeling promises to provide owners with a far better representation of their projects, increase the quality of both design and construction, and increase the speed of construction. BIM makes the handling of complex projects with enormous information requirements far easier. One of the attributes of high-performance green building projects is their reliance on significant additional modeling, additional specification requirements, and the need to track numerous aspects of the construction process, such as construction waste management, indoor air quality protection during construction, and erosion and sedimentation control. Additionally, quantities of recycled materials, emissions from materials, and other data must be gathered for green building certification. BIM has the capability of accepting plug-ins that can perform energy modeling and daylighting simulation and provide a platform for the data required by green building certification bodies. BIM software makes it relatively easy to select the optimum site and building orientation to maximize renewable energy generation and daylighting and minimize energy consumption. BIM is an important and potentially powerful tool that can further increase the uptake of green buildings by lowering costs. Although not strictly relevant to green building certification, it makes the process far easier and less costly by providing "one-stop shopping" for information (Kibert

2016). Differing perceptions and misaligned expectations of the benefits and expected outcomes of BIM and sustainable design adoption go some way to prevent a synthesis between the two approaches. There have been attempts to develop methods to calculate and quantify the benefits of BIM and related information system adoption but existing methods of analysis, lack industry acceptance and fail to provide a principal framework methodology that can measure comparable data across multiple projects (Dowsett 2013). During the design and preconstruction stages of a building, the most significant decisions regarding sustainable design features can be made (Azhar 2011). Linking new approaches to simulation and analysis within sustainable design to enhanced coordination of information via BIM throughout the construction process allows both reduction of rework and waste and the realization of 'designed-for-performance' new buildings and infrastructure through dialogic engagement of stakeholders (Dowsett 2013).

(Eddy Krygiel 2008) Suggested BIM can assist in the following areas of sustainable design:

- Building orientation (selecting a good orientation can reduce energy costs),
- Building massing (to analyze building form and optimize the building envelope),
- Day-lighting analysis,
- Water harvesting (reducing water needs in a building),
- Energy modelling (reducing energy needs and analyzing renewable energy options can contribute to low energy costs),
- Sustainable materials (reducing material needs and using recycled materials),
- Site and logistics management (to reduce waste and carbon footprints).

Design options for sustainability can be tracked and studied in a model along with spatial data to geographically locate and import building site information to place it within context and to contribute to an understanding of issues relating to climate, surrounding systems and resources. The building can then be adjusted and engineered using real coordinates to reduce the impact on and utilize sustainably the surrounding environment to reduce energy requirements, for example solar orientation (Hardin 2011). McGraw Hill Smart repot 2017 stated that the use of BIM to support sustainability goals is increasingly valuable. Tools for analysis and simulation are helping design professionals to generate higher performing design solutions, and contractors can leverage models in a variety of ways to improve the quality and reduce the environmental impact of their work. In addition, an emerging area of BIM activity relates to owners using models to improve building performance by optimizing facilities management. Contractors identified sustainability-related BIM activities they engage in either often or always:

- Almost two thirds (60%) of contractors are leveraging BIM to coordinate systems with the goal of improving energy performance, with high (67%) and very high (68%) BIM engagement firms doing it somewhat more than average.
- BIM for building performance in facilities management is a much more common practice among very high BIM engagement contractors (55%) than the average (44%) and appears to be taking hold in Brazil (57%) and France (55%) more than other regions.
- Prefabrication to create tighter building envelopes is less frequent overall (39%), but large companies (45%) exhibit an above-average involvement, and South Korean and French firms (57% and 55%, respectively) show leadership in this area.

- Although using BIM to manage waste more sustainably is the least practiced (23%) by all contractors, it scores more strongly with trade contractors (30%), perhaps because they have the greatest ability to impact material waste (McGrawHill 2017)

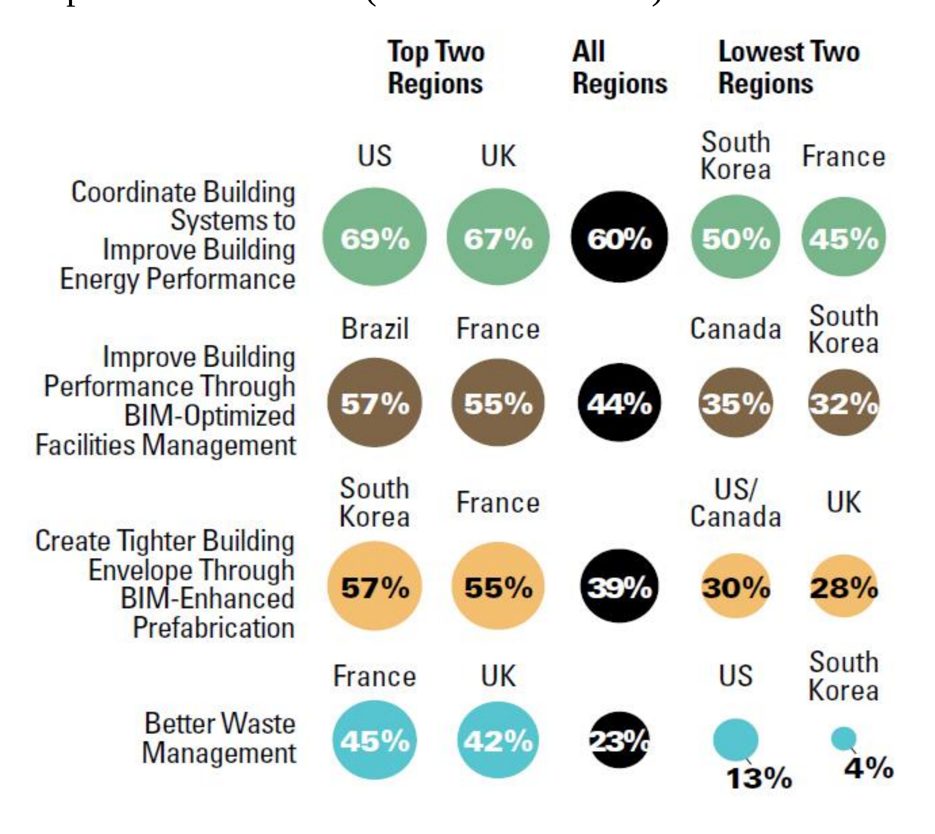


Figure 4-1: Percentage of Contractors That Are Conducting BIM Activities for Sustainability (McGrawHill 2017)

4.2 Evaluation of using BIM in Sustainable Design

The metrics chosen in most studies only provide an indicator of improvements; they do not provide a narrative of improvements, interdependencies of process change and technologies, training or information quality, and/or lessons learnt. Static notions of best practice neglect aspects of cultural environment, and social interaction and negotiation that could affect not only the outcomes but also the constructs themselves. Practitioners are encouraged to follow routine algorithms within a dominant culture of

compliance rather than to adopt innovative solutions to the inherently complex problems of organizational development and sustainable design that standardization should support. Exemplary buildings are achieved but they are accomplished in spite of the current traditional methods not because of them. BIM methodologies and tools, through the standardization of practices and processes, may free practitioners from the bureaucracy of traditional construction capacitating meaningful dialogic stakeholder engagement, practitioner discretion over design and improved decision-making by eliminating the restrictive conditions associated with traditional construction. Mechanistic conceptions of measurement methods across a disparate group of construction practitioners are difficult to achieve when the change required to improve is constrained by imbedded practice and professional structure and different path dependencies themselves have different embedded practices and professional structures. BIM methodologies and tools go some way to address these issues but to realize the benefits assessment methods must be diagnostic in order to identify the conditions required to successfully implement appropriate techniques relevant to the organization and projects. Renewed expectations and broader ranges of opportunities created by the adoption of BIM should inevitably produce improved organizational capabilities and subsequently value-added sustainable design. (Dowsett 2013)

4.3 Integration of BIM-Performance Analysis with Sustainable Design

From the AIA 2014 Progress Report, the AIA stated that energy modeling plays a critical role in improving building design and modeling early in the process helps ensure that performance is part of the decision-making process in the initial stages of a project. In addition to the importance that early energy modeling plays is, the magnitude of impact energy modeling has on a project. The AIA reported that nearly 50% of modeled projects met or came close to

achieving the 60% fossil fuel energy reduction, whereas nearly 80% of non-modeled projects fell below the 40% reduction range. More so, only 44% of projects were modeled in early design phases despite the fact that energy simulation carries more value when it guides big design decisions that are hard to undo later in the process (Alec 2014). Figure 4-2 shows the percent of improvement by Energy Use Intensity (EUI) reduction Bins. AIA stated that "energy modeling, an approach that can encourage more ambitious energy-saving design. The complexity and urgency of the AIA 2030 Commitment makes early, iterative energy modeling a basic part of design" (Alec 2014).

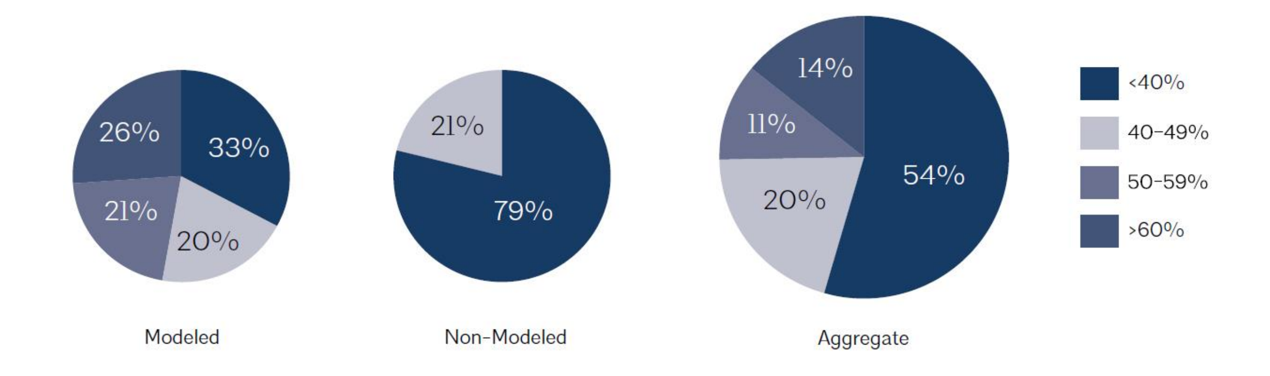


Figure 4-2: Percent Improvement by pEUI Reduction Bins, (Alec 2014)

In order to evaluate and optimize building performance, different analysis cycles should be part of an integrated design process. This challenges the current traditional design paradigm with a performance-based design method for many reasons;

- Traditional Method has deficiencies because; (1) it may include simplified assumptions based on rules-of-thumb, which can be inaccurate; (2) it may force an aesthetic feature without considering performance impacts; and (3) it doesn't provide performance measurement/evaluation of a certain design solution.

- Building Performance-Based Design Method has an ability to estimate the impact of design solution since: (1) performance measures are investigated with actual quantifiable data; (2) it uses detailed building models to simulate, analyze and predict behavior of the system and (3) can produce an evaluation of multiple design alternatives, (Ajla Aksamija 2012).

On other hand, it is very important for the design team to determine the proper Level of Development, LOD, and related analysis. The Level of Development (LOD) refers to the amount of information embedded in the model. The widely accepted example of LOD specification is the American Institute of Architects most recent BIM-protocol document, G202–2013, Building Information Modeling Protocol Form, (T. A. AIA 2013), as follows;

- **LOD 100:** The Model Element may be graphically represented in the Model with a symbol or other generic representation but does not satisfy the requirements for LOD 200. Information related to the Model Element (i.e. cost per square foot, tonnage of HVAC, etc.) can be derived from other Model Elements. The Model Element may be analyzed based on volume, area and orientation by application of generalized performance criteria assigned to other Model Elements.
- **LOD 200:** The Model Element is graphically represented within the Model as a generic system, object, or assembly with approximate quantities, size, shape, location, and orientation. Non-graphic information may also be attached to the Model Element. The Model Element may be analyzed for performance of selected systems by application of generalized performance criteria assigned to the representative Model Elements.
- **LOD 300:** The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of quantity, size, shape,

location, and orientation. Non-graphic information may also be attached to the Model Element. The Model Element may be analyzed for performance of selected systems by application of specific performance criteria assigned to the representative Model Element.

- **LOD 400:** The Model Element is graphically represented within the Model as a specific system, object or assembly in terms of size, shape, location, quantity, and orientation with detailing, fabrication, assembly, and installation information. Non-graphic information may also be attached to the Model Element. The Model Element may be analyzed for performance of systems by application of actual performance criteria assigned to the Model Element.
- **LOD 500:** The Model Element is a field verified representation in terms of size, shape, location, quantity, and orientation. Non-graphic information may also be attached to the Model Elements (T. A. AIA 2013).

4.4 Link between BIM and Energy Simulation

In 2015 M. Senave & S. Boeykens conducted five studies to examine the link between BIM and energy simulation and they conclude that, "a whole arsenal of tools exists to export data from a BIM model in favor of an energy simulation model. Yet automating the transfer to an application is cumbersome, time-consuming and may give rise to errors and misinterpretations. The development of tools to accomplish dynamic simulations by specialized software like "Energy-Plus" through the Industry Foundation Classes (IFC) standard is still in an experimental stage but offers good prospects for the operation of extensive data exchange and analysis. Therefore, there are several promising developments of BIM applications and energy simulation tools. (M. Senave 2015). With BIM, designers can optimize the building design efficiently in the very early stages of the whole process

and produce a better solution. Table 4-1 summarizes the major contributions of BIM to sustainable building design, (Kam-din Wong 2013).

Table 4-1: Summary of BIM for sustainable design (Kam-din Wong 2013)

	Functions	Benefits	Sustainable achievements
BIM Inherency + → BIM-based Analysis Tools	3D Model Visualization Clash Detection Compliance with Regulations Energy Analysis; Solar Analysis → Thermal Analysis Lighting Design Acoustic Analysis Ventilation and Air Flow Materials/Resource Management	Integrated Project Delivery Design Optimization Better Communication and Coordination → More accurate and efficient	Energy Reduction Water Conservation Wastage Lessen IEQ Improvement

4.5 Limitation of BIM-Based sustainable tools

There is, however, currently a limit to the information generated by the BIM models that can be used for sustainability analysis. Such automated, streamlined systems cannot yet, therefore, replace manual environmental assessment methods, but could certainly compliment them, subject to manual checking (Zaid 2015).

4.6 BIM and LEED credits

The major barrier that prevents projects pursuing LEED® certification stems from the increased upfront cost mostly attributed to investment in new technologies, materials, administrative fees and overhead costs for certification (W. W. Issa 2010). The advent of BIM technology has caught the attention of professionals as providing a promising new way to address LEED® certification requirements by taking advantage of the functionalities

in current BIM solutions. Some well-known applications of BIM include the use of BIM to conduct building energy simulation, daylighting design, and material inventory. Another good potential use for BIM would be in preparing the documentation to be submitted for review by USGBC to determine whether or not a LEED® point should be awarded. USGBC is quite strict on documenting the project delivery process while project teams oftentimes find it tedious to collect and input data into the documentation templates provided. Even though most of the information should readily be available it is not there because of inconsistent record-keeping, or lack of tools that allow such information to be captured. With BIM, a centralized model will be available to capture, manage, monitor and update all project information throughout the building's life cycle. Then, the project team simply needs to define what information is needed to prepare the corresponding document and submit it to USGBC for review (W. W. Issa 2010). In order to improve the benefit of using BIM in a part of LEED certification process, Chena and Nguyen developed a framework for the integration of BIM and Web Map Service (WMS) technologies for location and transportation analysis in the green building certifications. Using Autodesk Revit API and Google Maps API as the development tools, this research converted the integration model into the BIM-integrated plugin in Autodesk® Revit. The plugin is used to streamline the certification process of site location and transportation analysis in LEED 2009, Figure 4-3 shows the user interface of LEED credit SSc2 – Option 1 (Development density). And
Figure 4-4 shows SSc2 Option 2 user interface. Most countries are promoting the use of new technology in sustainable construction. If the BIM technology is involved efficiently in LEED certification, the information will be automatically reprocessed without additional manual calculation or using

other methods, it can reduce costs of calculation and enhance the rate of green building application in the world. Table 4-2 shows Sustainable Sites Credit SSc2 and SSc4.1 as LEED NC 2009 requirements and the potential points aimed to be calculated automatically by proposed add-in (Po-Han Chena 2017).

Table 4-2: Sustainable Sites Credit SSc2 and SSc4.1 (LEED NC 2009)

Credits	Intents	Options	LEED Pts
Credit SSc2: Development Density and Community Connectivity	To channel development to urban areas with existing infrastructure, protect Greenfields, and preserve habitat and natural resources.	**Option 1:** Development Density	5 points
		Option 2: Community Connectivity	
Credit SSc4.1: Alternative Transportation - Public Transportation	To reduce pollution and land development impacts from automobile use.	**Option 1:** Rail station, Bus rapid transit station & ferry terminal Proximity	6 points
		Option 2: Bus stop Proximity	

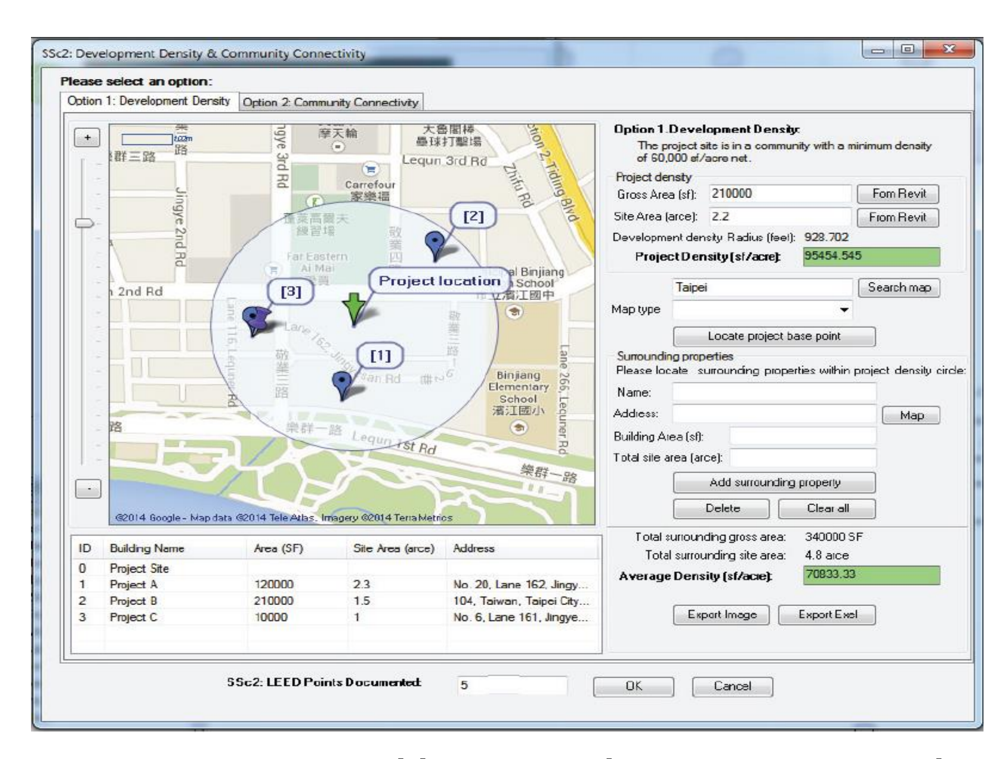


Figure 4-3 : BIM integration model in LEED credit SSc2 – Option 1: Development density (Po-Han Chena 2017)

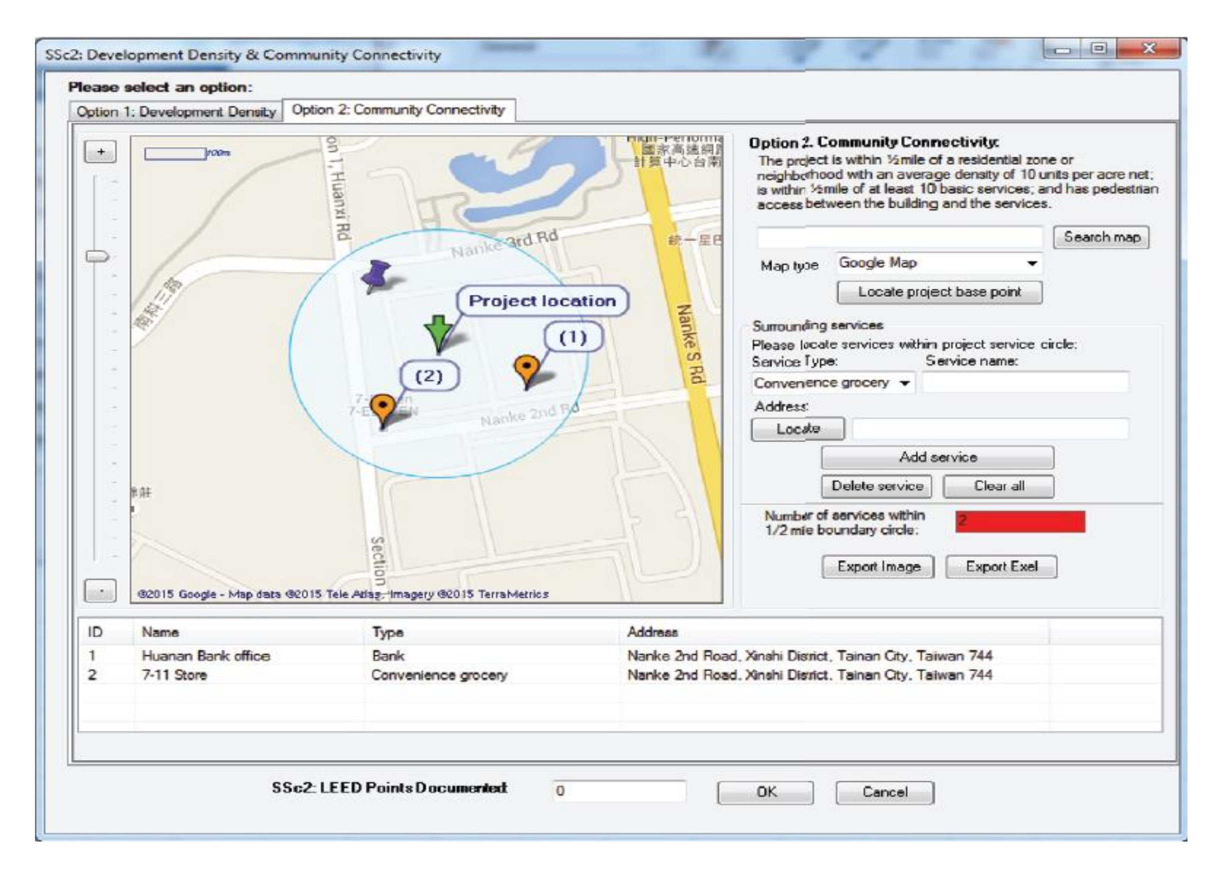


Figure 4-4: SSc2 Option 2 user interface (Po-Han Chena 2017)

Azhar demonstrated the ways designers and planners may use BIM for various sustainability analyses in pursuit of LEED® certification. The scope of the research was limited to nonresidential new building projects only. And he concluded that, the results of sustainability analyses software can be used to directly, semi-directly or indirectly generate LEED® documentation. Up to 17 LEED® credits and 2 prerequisites may be documented using results generated by BIM-based sustainability software; however; only 5 credits and one prerequisite have been verified in this study so far. BIM-based sustainability software generates results very quickly as compared to the traditional methods. In other words, a building information model can be used partially to run these analyses. This could save substantial time and resources, (W. A. Salman Azhar 2011). Furthermore, M. Solla and his team verified the BIM application in achieving credits for an identified case study and achieved 55%

of LEED 2009 credits, i.e. equivalent to the silver level certification. M. Solla presented that, the LEED® 2009 rating system has a total of 69 credits. Based on an analysis of BIM software and sustainability, 38 credits can be found directly from BIM, whereas 31 credits require supporting documentation that cannot be prepared by BIM software. For example, some credits require a narrative that is submitted along with the necessary computations (Mohmed Solla 2016). Table 4-3 illustrates the total points that can be achieved with BIM and the examples of the BIM tools. As shown in the table, LEED® 2009 has six criteria with the maximum points of each. Water efficiency has full points that can be earned using BIM and minimum points achieved from credits of indoor environmental quality. In this case, the project receives a silver certification in the LEED rating system.

Table 4-3: BIM achievement in LEED 2009 rating system (Mohmed Solla 2016)

Criteria	Maximum Points	Weighting	BIM Points	BIM Weighting	BIM Tool
Sustainable Sites	14	20.3%	6	8.7%	Revit
Water Efficiency	5	7.2%	5	7.2%	Revit VE
Energy& Atmosphere	17	24.6%	10	14.5%	VE
Materials & Resources	13	18.9%	9	13.1%	Revit
Indoor Environmental Quality	15	21.8%	4	5.8%	Revit VE
Innovation & Design Process	5	7.2%	4	5.7%	Revit VE
Total	69	100%	**38**	55%	

4.7 BIM and GIS integration

Buildings cannot be used for their intended purpose without utilities. Maintenance workflows require work to be performed from the inside and outside of the buildings. The inside information can be extracted from a fully built building information model, and the outside information can be extracted

from a Geographical Information System (GIS) map (R. L. Issa 2012). The separation of low energy building design and urban energy planning process is mainly resulted from the use of different information and modeling systems. BIM gives description of the building in deep geometrical and attributive details. Geographic information system (GIS) is the most important tool to describe a digital city in multi-rate, multi-scale and space-time dimensions. Building information models provide a very rich data source for properties about all of the building elements (e.g., identification, maintenance information, and life cycle and condition-based information). These properties are inevitable components of any construction project. Moreover, descriptive information (e.g., transportation network, asset locations, etc.) in GIS should be used to model temporary components, locate temporary facilities, reduce transportation and logistics costs, and many other applications, (Ebrahim P. Karan 2015)

4.8 Database management system (DBMS)

Database management system is a collection of programs, which can control and manage a database structure. DBMS provides controlled access to the data stored in the database. The use of a computer database can make for efficient management of the data that can be stored, shared and integrated. The database structure itself is stored as a collection of files. The only way to access this information; is by using a database management system (DBMS), (Jalaei 2015).

4.9 Application Programming Interface (API)

In recent years, application programming interfaces (APIs) have begun to play an increasingly important role in defining how remotely hosted services accept and generate information. APIs include protocols offered by remotely hosted services that provide access to third parties to resources associated with

the remotely hosted services. APIs are frequently used to manage communication between one or more parties on data networks such as the Internet (David-Tribbett 2012). Revit is the application programming interface-API. It has enabled the creation of thousands of plug-ins to customize and automate Revit, and many of the tools have built for Revit wouldn't be possible without it. There are new tools created, every week tools to increase productivity, to better manage models, and to create stunning client presentations. This thriving ecosystem means that Revit is not limited by what Autodesk can build; it can be customized to suit targets (Lance Kirby 2018).

4.10 Integration and Interoperability

The building life cycle involves organizations with different responsibilities and functions. However, there is no specific BIM tool that can support all the functions needed at all stages of the building life cycle. Exchanging the data between applications is essential to the project team (Jalaei 2015). Model information can be exchanged between two different software tools in four ways as (Jalaei 2015):

- Direct links between specific BIM tools;
- Proprietary Exchange File Format;
- Public Level Exchange Formats;
- XML-based exchange formats.

As the industry continues to build processes around the technology behind BIM, its potential continues to grow. Many applications are possible using building information modeling (Lance Kirby 2018). Groups from a number of regional chapters around the world are generating information exchange standards that will soon have a profound impact on the ways in which we share model data with our clients and partners (Lance Kirby 2018). The following are some of the latest developments:

- Industry Foundation Classes (IFC) version 4
- Construction Operations Building Information Exchange (COBie)
- Speci_ers' Properties Information Exchange (SPie)
- BIM Collaboration Format (BCF)

4.11 Industry Foundation Classes (IFC)

Industry Foundation Classes, or IFC for short, is a global standard used to describe, share and exchange construction and facilities management information. As a data format IFC is neutral (not the product of or favouring any particular vendor) and non-proprietary (NBS 2018). IFC is one of five types of open standard in the buildingSMART portfolio that each perform different functions when it comes to the delivery and support of assets in the built environment (BuildingSMART, IFC Introduction 2018). Using IFC means that construction professionals can use the software application(s) of their choosing to work with data. IFC is supported by about 150 software applications worldwide and this kind of interoperability is crucial as construction becomes increasingly collaborative (NBS 2018). The history of IFC can be traced back to 1994. IFC was an output of the Industry Alliance for Interoperability, a consortium founded by Autodesk. The consortium became the International Alliance for Interoperability in 1997 and is now known as buildingSMART – a not-for-profit organisation that describes itself as the international home of openBIM. It promotes IFC as a neutral product model supporting the building lifecycle and opens up membership to all interested parties. In 2013 IFC was registered with the International Standardisation Organisation as ISO16739 'Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries'. The IFC schema is regularly evolving with the current version, released in 2013, known as IFC 4. IFC4 extends support for parametric and geometries,

extends the building services and structural domain and offers a simple XML format. IFC5 is in the pipeline with further provision for parametric capabilities and inclusion of the infrastructure domain (NBS 2018).

The IFC specification is developed and maintained by buildingSMART International as its "Data standard". Since IFC4 it is accepted as ISO 16739 standard (BuildingSMART, IFC Overview 2018). The specification of the IFC standard includes for each major and minor edition:

- The IFC Specification html documentation (including all definitions, schemas, libraries)
- The URL for the IFC EXPRESS long form schema
- The URL for the ifcXML XSD schema

IFC data files are exchanged between applications using the following formats listed in Table 4-4 and should be indicated by the published icons:

Table 4-4: IFC Data File Formats and Icons (BuildingSMART, IFC Overview 2018)

.ifc	IFC data file using the STEP physical file structure according to ISO10303-21. The *.ifc file shall validate according to the IFC-EXPRESS specification. This is the default IFC exchange format.	
.ifcXML	IFC data file using the XML document structure. It can be generated directly by the sending application, or from an IFC data file using the conversion following ISO10303-28, the XML representation of EXPRESS schemas and data. Note: an .ifcXML file is normally 300-400% larger then an .ifc file.	xml
.ifcZIP	IFC data file using the PKzip 2.04g compression algorithm (compatible with e.g. Windows compressed folders, winzip, zlib, info-zip, etc.). It requires to have a single .ifc or *.ifcXML data file in the main directory of the zip archive. Note: an .ifcZIP files usually compress an .ifc down by 60-80% and an .ifcXML file by 90-95%.	zip

4.12 Construction Operations Building Information Exchange (COBie)

COBie is an information exchange specification for the life-cycle capture and delivery of information needed by facility managers. COBie can be viewed in

design, construction, and maintenance software as well as in simple spreadsheets. This versatility allows COBie to be used all projects regardless of size and technological sophistication. The COBie specification identifies the content of the information that must be captured and exchanged at each phase of the project to begin to reduce the waste associated with the current paper process. Between 2005 and 2009 COBie has grown from an initial idea to an internationally recognized standard implemented in commercial software across the globe. The COBie project has been led by the Engineer Research and Development Center, Construction Engineering Research Laboratory “a laboratory of the U.S. Army, Corps of Engineers” (NIBS 2018). Successful commercial implementations of COBie have been demonstrated many times since July 2008. For links to these exchanges, In July 2008, participants expressed interest in a fully international version of COBie specification. In Dec 2009 the COBie team released the international COBie and the Facility Management Handover Model View Definition formats. COBie is now mandated for public building projects in the U. K. (NIBS 2018).

4.13 gbXML

The Green Building XML schema, or "gbXML", was developed to facilitate the transfer of building information stored in CAD-based building information models, enabling interoperability between disparate building designs and engineering analysis software tools. This is all in the name of helping architects, engineers, and energy modelers to design more energy efficient buildings.Today, gbXML has the industry support and wide adoption by leading Building Information Modeling (BIM) vendors including Autodesk, Trimble, Graphisoft, and Bentley. With the development of export and import capabilities in over 40 engineering and analysis modeling tools, gbXML has become a defacto industry standard schema. Its use dramatically streamlines

the transfer of building information to and from architectural and engineering models, eliminating the need for time consuming plan take-offs. This removes a significant cost barrier to designing sustainable and energy efficient buildings. It enables building design teams to truly collaborate and realize the potential benefits of Building Information Modeling. In June of 2000, the gbXML schema was submitted by a company called Green Building Studio for inclusion in aecXML(TM), the industry-led initiative launched by Bentley Systems. Shortly thereafter, gbXML became the draft schema for the Building Performance & Analysis Working Group. In 2009, gbXML was spun off from Green Building Studio to become a stand-alone entity and things really took off then: funding was secured, the schema was drastically improved, a new website was launched, and a community of thousands of architects, engineers, and energy modelers attended live webinars explaining the benefits of gbXML. Today, gbXML is funded by organizations such as the U.S. Department of Energy, the National Renewable Energy Lab (NREL), Autodesk, Bentley Systems, and others. Version 6.01 - November 2015 is the latest version of gbXML schema (gbXML 2018).

CHAPTER 5

BIM & Green Building status in MENA Countries

5.1 Introduction

With the increasing demand for more energy-efficient buildings, the construction industry is faced with the challenge to ensure that the energy performance predicted during the design is achieved once a building is in use. Energy simulation tools are increasingly used for analysis of energy performance of buildings (Abul Abdullah August, 2014). Over the last decade, a large number of building performance simulation (BPS) tools have been developed to help engineers during late design phases. Such tools were developed to produce data concerning buildings' numerical modelling, simulating the performance of real buildings. Those energy BPS tools require a complicated representation of the building alternatives that require specific and numerical attributes of the building and its context. However, during the last ten years, a range of design tools has been available to help architects in the design of more energy efficient buildings. Those tools are labelled "guidance tools", which were developed to facilitate decision making prior to design. They range from quite simple pre-decision evaluation and analysis tools to parametric and optimization decision tools that aim to inform the design and integrate BPS during the early design process (Attia 2012).

5.2 Status of using BIM and Green Building in MENA Countries

The following questionnaire investigates five-sensitive areas of the integration process in construction management field, which is still obscurity in the Middle East AEC market. The analysis of this questionnaire introduces the current status of using BIM-Based tools in sustainable design process in the Middle East area. As before discussed, a questionnaire was directed to

professionals and experts in the following fields: (Sustainability, BIM-based simulation, Energy performance analysis, Design decision makers and related knowledge fields. The questionnaire targeted sample was selected from worldwide companies especially those working in Egypt and Saudi Arabia AEC field. The questionnaire focused on international and regional firms, which already have experience in Middle East and North Africa (MENA) region (Appendix A) shows a list of practitioners companies. The main objective of the questionnaire designed to investigate to what extent the AEC market benefited of using BIM-based tools in sustainable projects by monitoring the following five experience parameters:

- Sustainable Design and common used rating systems
- Building Information Modeling (BIM) and common used programs
- Building Performance Analysis (BPA) and common used methods
- The accuracy of results of simulation techniques
- The future of using BIM-based simulation tools in sustainable design

5.3 The Questionnaire respondents' profile

The questionnaire sent in electronic form to 150 AEC practitioners and academics. Those were randomly chosen from published companies addresses, Famous International & regional firms in AEC field and business contacts among MENA area. Several responses contained invalid answers, therefore were disregarded. Table 5-1 shows the respondents frequency.

Table 5-1: The questionnaire respondents' location

LOCATION	FREQUENCY	PERCENT	VALID PERCENT
MENA (MIDDLE EAST AND NORTH AFRICA)	100	80.6%	80.6%
ASIA-PACIFIC	15	12.2%	12.2%
EUROPE	5	4.1%	4.1%
USA	4	3.1%	3.1%
TOTAL	**124**	**100%**	**100%**

The response rate was about 83%. Thus, 124 responses were gathered, 100 from the MENA, 15 from Asia-Pacific and 9 from USA & Europe. The research checked the appropriate sample size according to the level of precision, the level of confidence or risk, and the degree of variability in the attributes being measured. Yamane (1967:886) provides a simplified formula to calculate sample sizes. This formula is shown below. Z=1.64 at 95% confidence level and P = 0.2, e = 0.08 are assumed for Equation 1.

$$n = \frac{Z^2 \, p(1-p)}{e^2}$$

Equation 1

Where (n) is the sample size, (N) is the population size, and (e) is the desired level of precision, (p) is the estimated proportion of an attribute that is present in the population. When this formula is applied to the above sample, we get Equation 2.

$$n_0 = \frac{1.64^2 * 0.2(1-0.2)}{(0.08)^2} \cong 68$$

Equation 2

In addition, the following analysis conducted by SPSS software in order to check scientific basis of the questionnaire:

1. Check frequencies and missing cases. (Appendix C1) shows the frequency table
2. Reliability analysis. (Appendix C2) shows the Item-Total Statistics.
3. Bivariate Correlations. (Appendix C3)

Table 5-2: Reliability Statistic result by SPSS

<table>
<tr><th colspan="2">Reliability Statistics</th><th rowspan="4">Cases</th><th></th><th>N</th><th>%</th></tr>
<tr><td colspan="2"></td><td>Valid</td><td>124</td><td>100</td></tr>
<tr><td>Cronbach's Alpha</td><td>N of Items</td><td>Excluded[a]</td><td>0</td><td>0</td></tr>
<tr><td>.915</td><td>26</td><td>Total</td><td>124</td><td>100</td></tr>
<tr><td colspan="6">a. Listwise deletion based on all variables in the procedure.</td></tr>
</table>

5.4 The Questionnaire results

The results reflect that the sustainable design began to prosper in the last decade in (MENA) region. 62 respondents claimed that they have using (LEED®) rating system in MENA by 25 regional companies and 37 International companies (see Figure 5-1)

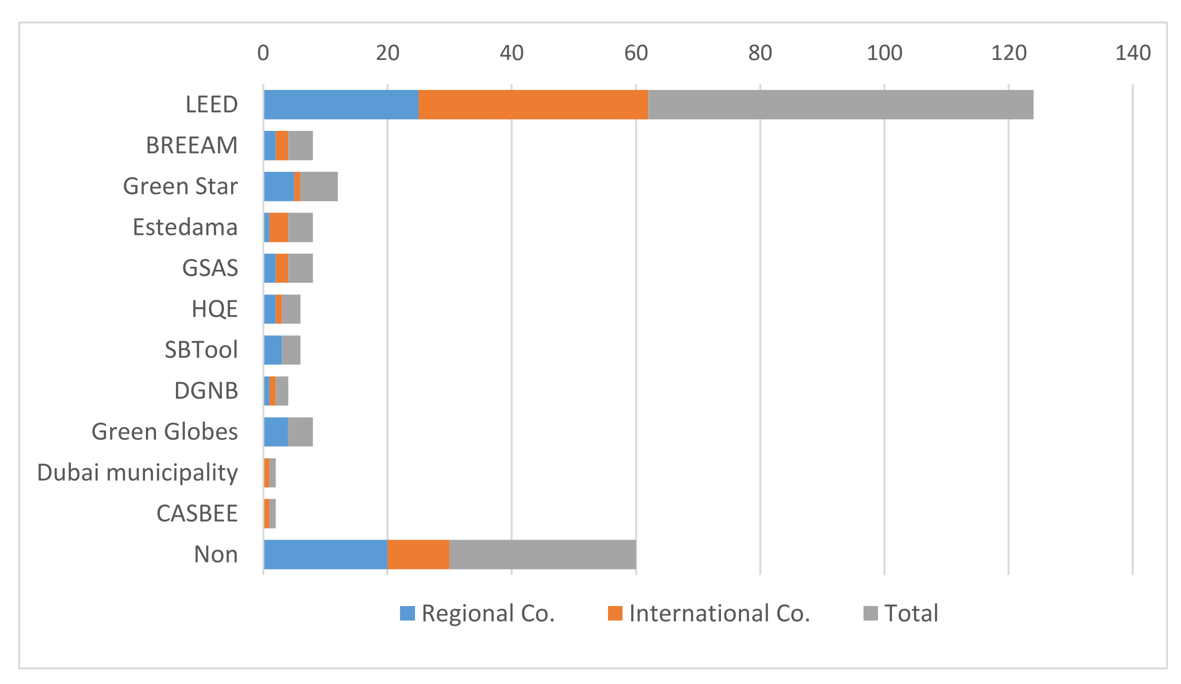


Figure 5-1: Green Building Tools used in MENA.

In addition, 116 respondents declared that they are using (BIM) programs in the design process for modeling, 75 of them basically use (Autodesk® Revit®) software for modeling by 33 regional companies and 42 International companies.

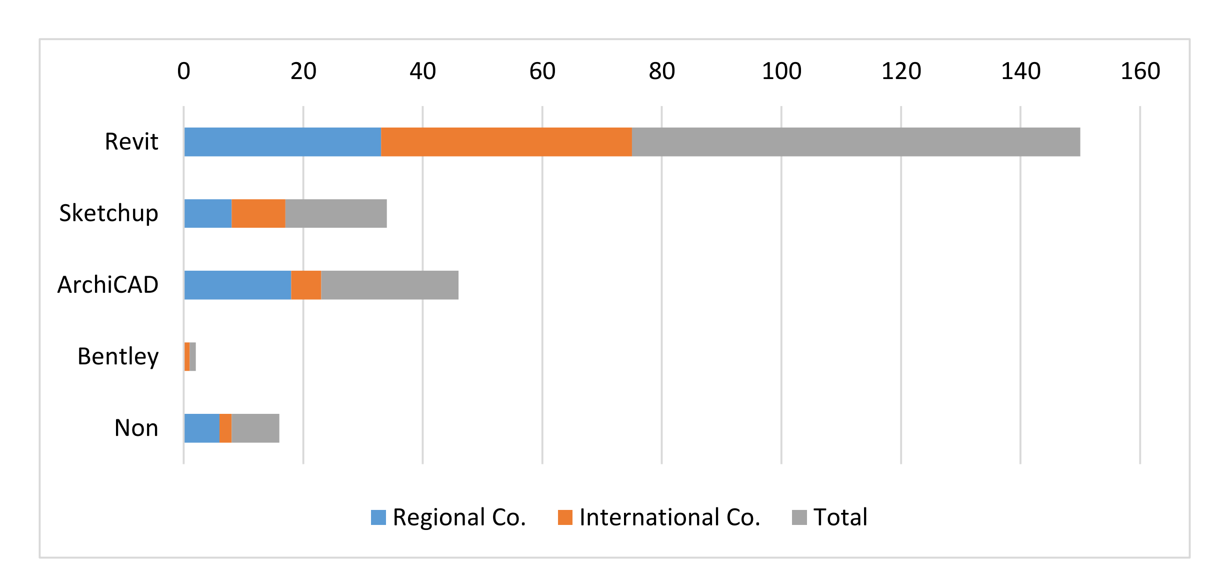


Figure 5-2: BIM Tools used in MENA.

But also, the questionnaire reflects that, using BIM in environmental studies and energy simulation still in its beginnings, only 36 respondents stated that they have practice general environmental analysis, 23 practices at least one of the environmental studies like; (Building orientation, Building mass, Solar and shadows, Thermal properties of envelope materials, Wind and Potential renewable energy saving). And 49 already using BIM in energy performance analysis. Figure 5-3 represents the respondents' answers of the considered environmental studies for simulation.

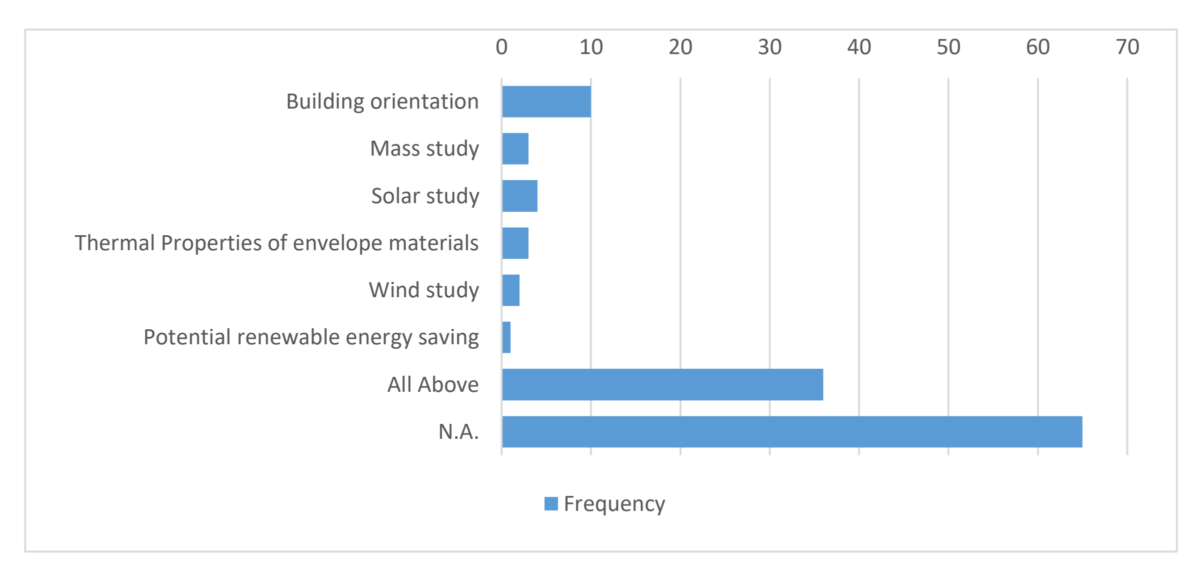


Figure 5-3: Almost environmental studies practices using BIM

In addition, the questionnaire results reflect that, design team may still use traditional methods to evaluate building performance even if use simulation tools. 18 respondents stated they are using traditional method, 15 respondents using BIM-based simulation tools and 19 respondents use both methods. This may be due to a lack of confidence in the simulation outputs. Figure 5-4 shows using of performance analysis methods.

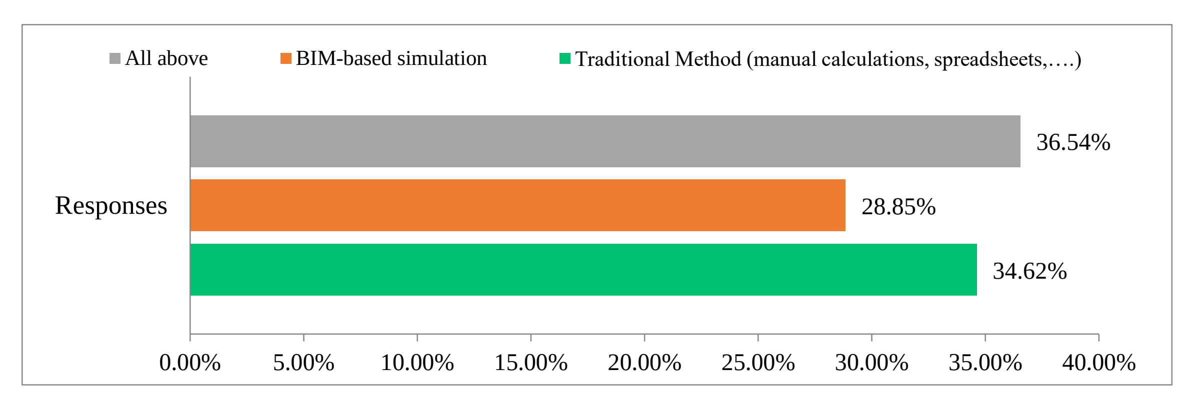


Figure 5-4: Using of performance analysis methods -Questionnaire Result.

Figure 5-5 illustrates the conducting of building performance analysis during project phases. 19 respondents are conducting building performance analysis in concept design phase, 19 respondents in the schematic design phase, 20 respondents in the development design phase, 11 in tendering phase, 19 in construction phase and 8 respondents are conducting BPA in operation and maintenance phase.

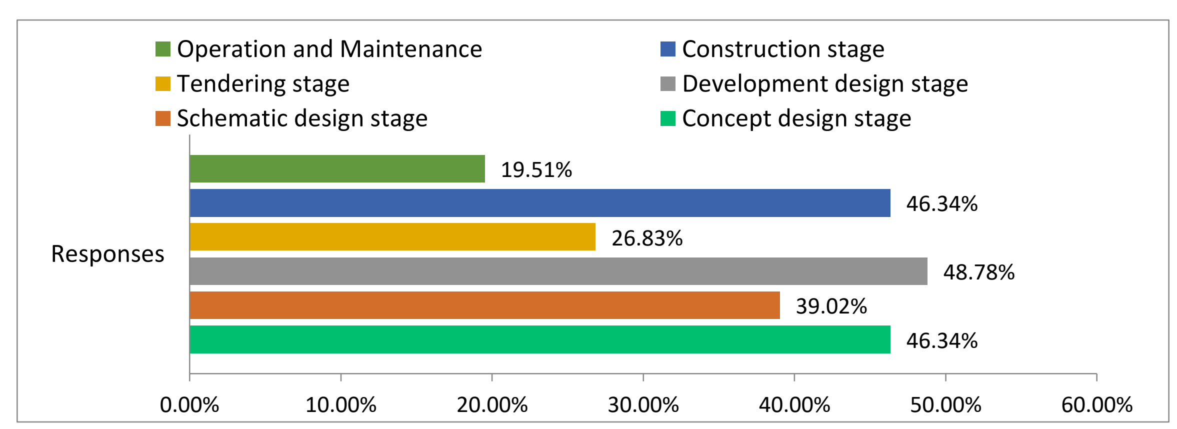


Figure 5-5: Building performance analysis during project phases - Questionnaire Result.

Figure 5-6 reflects the reasons of conducting building performance analysis. 41 respondents are conducting building performance analysis just upon owner's request, 16 respondents said that, the BPA is a part of the company policy as an environmental responsibility. 2 respondents are conducting BPA because it is a mandatory in their country laws (municipality regulations, License requirements, etc.), the remaining respondents skipped this question.

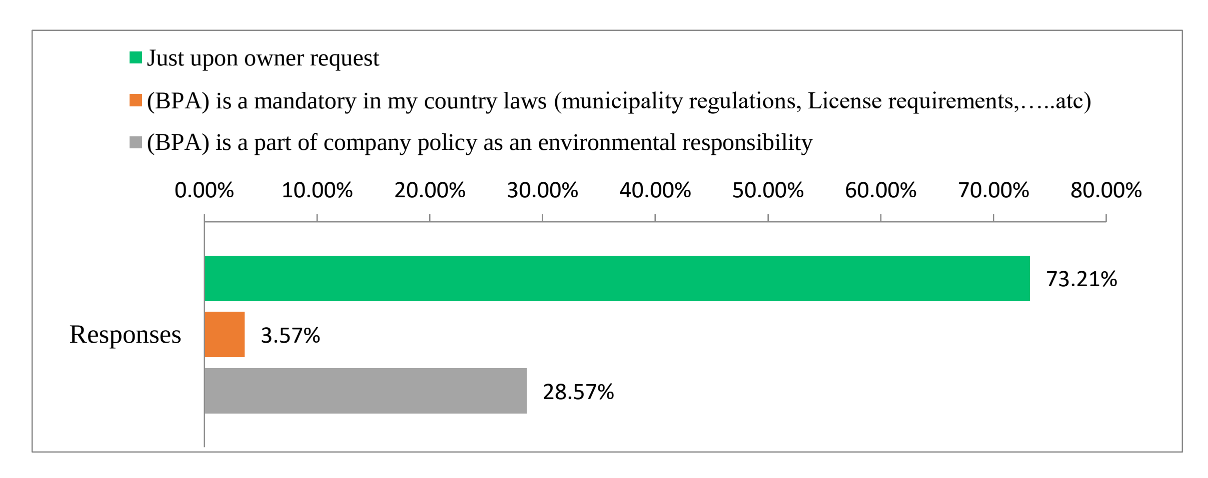


Figure 5-6: reasons of conducting building performance analysis - Questionnaire Result.

Figure 5-7 illustrates the specialists' evaluation of the benefits gained from using BIM-based simulation tools and its effect on design outputs. 29 respondents thought it is extremely beneficial, 23 respondents said it is somewhat helpful and 3 respondents said not helpful at all may be because they have not enough experience in this field.

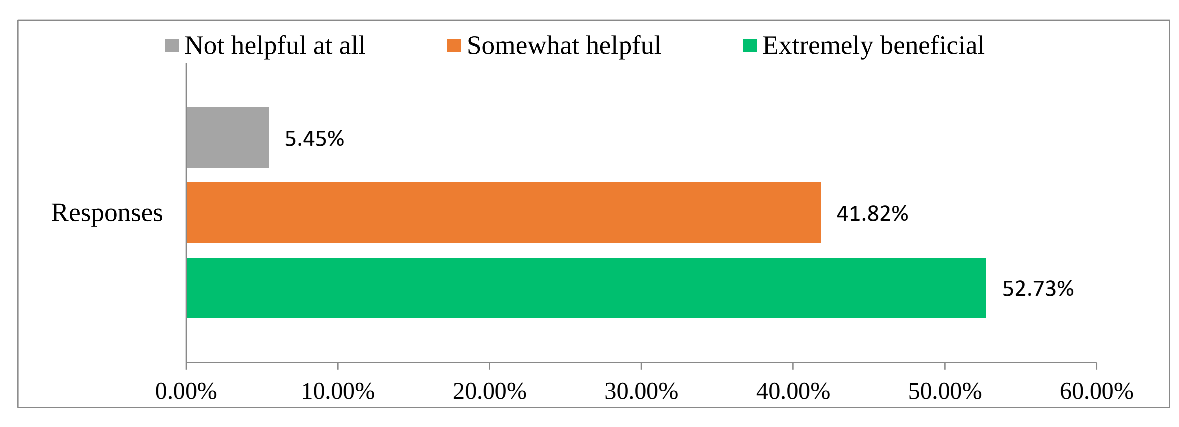


Figure 5-7: BIM-based simulation tools benefit for design output - Questionnaire Result.

Figure 5-8 illustrates the specialists' evaluation of the simulation outputs accuracy. 10 respondents thought it is excellent, 34 respondents said it is good, 12 considered that it just gives a feasible perception and 4 respondents said it's producing confused results, may be because they have not enough experience in this field.

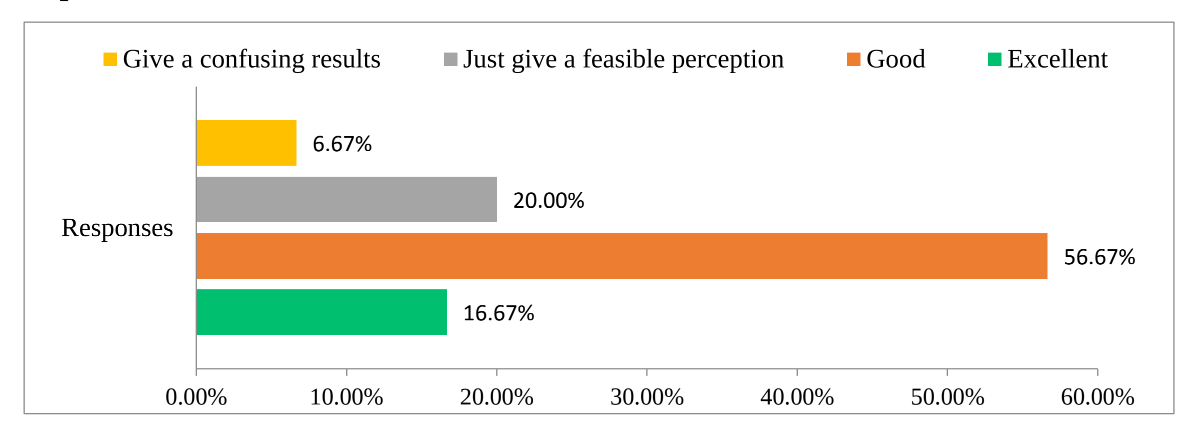


Figure 5-8: Accuracy of simulation results - Questionnaire Result.

Moreover, Figure 5-9 represents the survey of environmental studies, which considered in design and used for preparation of simulation process.

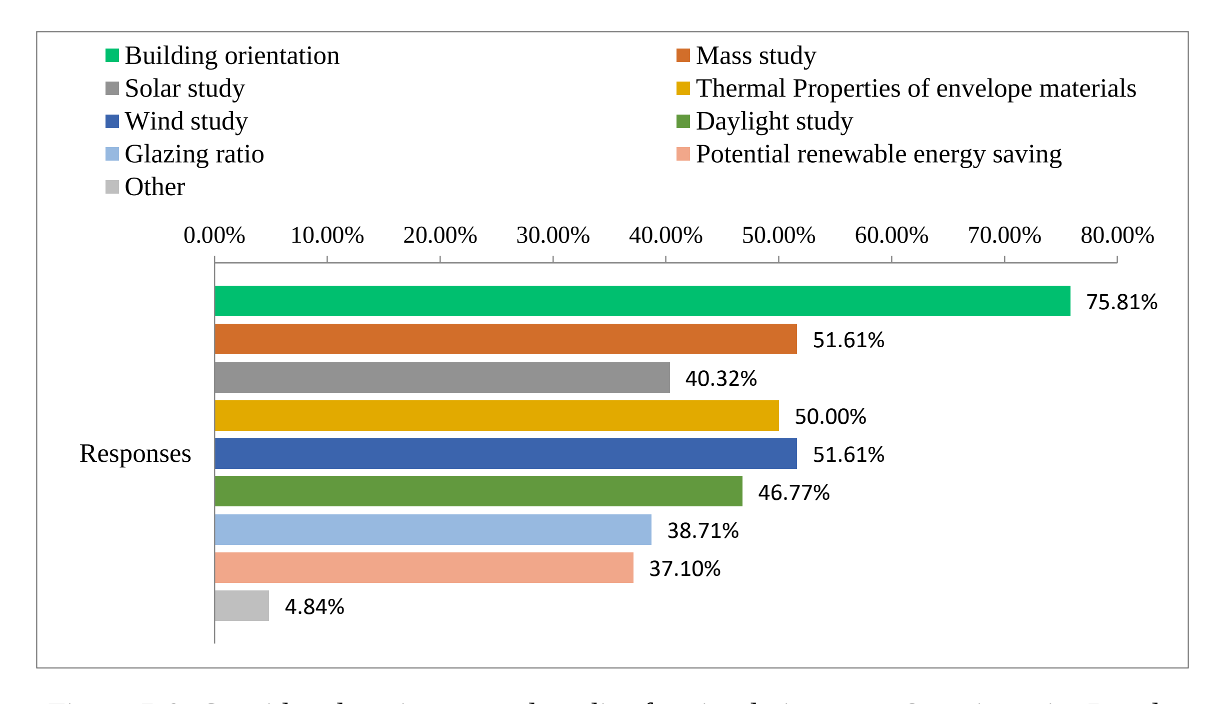


Figure 5-9: Considered environmental studies for simulation run - Questionnaire Result.

5.5 The questionnaire Findings

The questionnaire results reflect the following development in the MENA region:

- Increased attention to environmental design during the last decade
- Increased attention to BIM tools during the last five years
- (LEED®) is the most used green building rating system,
- Autodesk® Revit® is the most used BIM-based software,
- Using BIM in field of environmental Energy analysis still limited,
- Practice of performance analysis in all design phases still limited,
- The main reason of practicing performance analysis is up to owner's request not due to commitment toward a government roles or international environmental initiatives,
- It was difficult to determine the accuracy of the simulation results because of the divergence of practices. However, there is a tendency for the simulation results are helpful.

More analysis applied on the questionnaire, see Appendix A.

CHAPTER 6

Proposed Integration Process

Based on the literature review, questionnaire results and applied case study, the research introduces a simplified approach for more organized integration process between the design team and local authorities. In addition, to facilitate information gathering and reserve time and efforts in design phases. Figure 6-1 represents the proposed integrated workflow of using BIM-based software in sustainable building design. It starts from importing exchange file with extension (.IFC) that contains a 3d geospatial map of project location surrounding area with minimum radius buffer (800m). The IFC map file considered to be owned by local authorities or city server. Design team has aligned the project conceptual model with the imported IFC map and real geographic location. Furthermore, the 3D-model developed with the required details depends on design Level of Development (LOD100 & 200). In this LOD, a Revit API Add-in were developed to extract information required to calculate points could be achieved related to the following LEED v4 credit categories: (Location & Transportation, LTc1, LTc2, LTc3, LTc4, LTc5 and, LTc6) and (Sustainable Sites, SSc3). Then, develop the 3d model through (LOD 300 & 400) in conjunction with other BIM Simulation and Optimization tools like (Green Building Studio, Insight 360 and Revit API Add-ons); in order to extract the remaining information for LEED v4 credit categories. The research proposes that the design team shall be linked with many outsources using BIM exchange files including related GIS data. Accordingly, the concerned government departments have to develop a responsibility assignment matrix (RAM) protocol with the design firms.

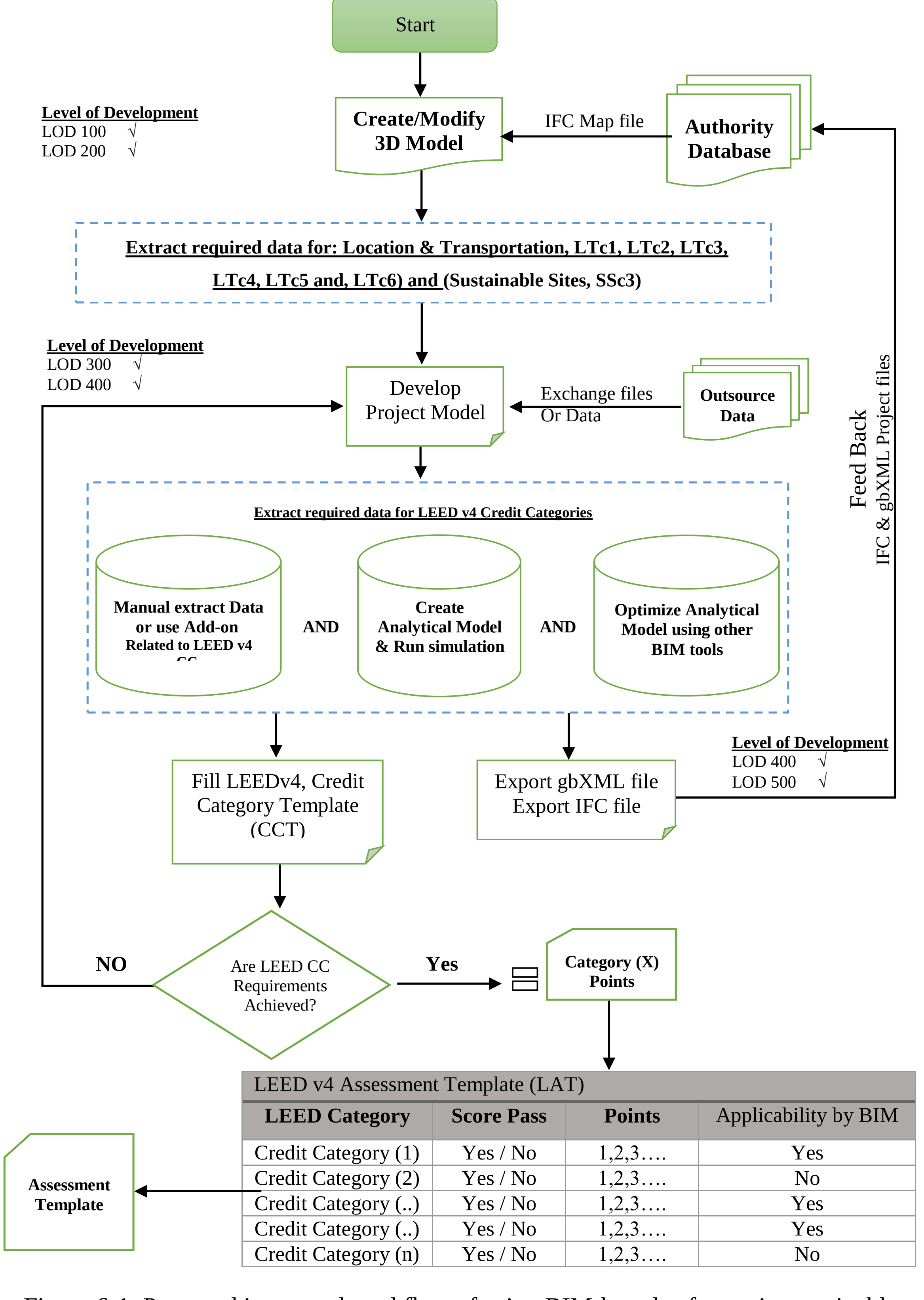


Figure 6-1: Proposed integrated workflow of using BIM-based software in sustainable design process

Meanwhile, the design team should develop a spreadsheet including the expected outsources and classifies the required data from each source. One of BIM programs advantages is the ability to accept “Add-ons”. The exploit of these advantage lead to save time and cost of the design team during modeling the project. Particularly, if these “Add-ons” are employed to support LEED certification process.

6.1 Outputs of proposed framework

A BIM model usually includes the 3D shape of the objects, but can also include things such as their cost, installation date, or operating parameters. We can attach practically infinite additional data to any object or category of objects in a BIM database, and use that data to manage information flow across multiple life-cycle phases and between multiple parties. By creating a single source of truth and making project information available across the design, construction and operation teams, we increase our accuracy and efficiency, and can realize significant savings on the life-cycle cost of operation for an asset (AECOM 2017). The research directed the BIM tools to introduce more specific deliverables by analyze the required information for a particular target result. The outputs of Add-ons, simulation and indirect collected information has been transferred to a predesigned simple spreadsheet contains the maximum potential points that are likely to be obtained as per LEED- v4 requirements. Furthermore, a feedback report and exchange file with extensions (.IFC & gbXML) format exported to the government departments to be included in the city server (and/or) regional planning database. The research considers the exported (.IFC & gbXML) files are the core of future City Information Modeling (CIM). The final pre-assessment spreadsheet is and feedback files are the final output of the proposed framework.

6.2 BIM software

Based on the questionnaire results, (Autodesk® Revit) is the common used BIM-based software for modeling. In addition, the cloud-based (Autodesk® Green Building Studio & Autodesk® Insight360) are recommended for simulation and optimization processes. There are several of BIM software are used for specific sustainable studies like; (Location & Transportation Add-in, Autodesk® CFD, daylighting analysis plugin and EXNO plugin for acoustic analysis). Figure 6-2 shows the common used modeling software, while, Figure 6-3 shows the common used energy simulation tools in MENA area

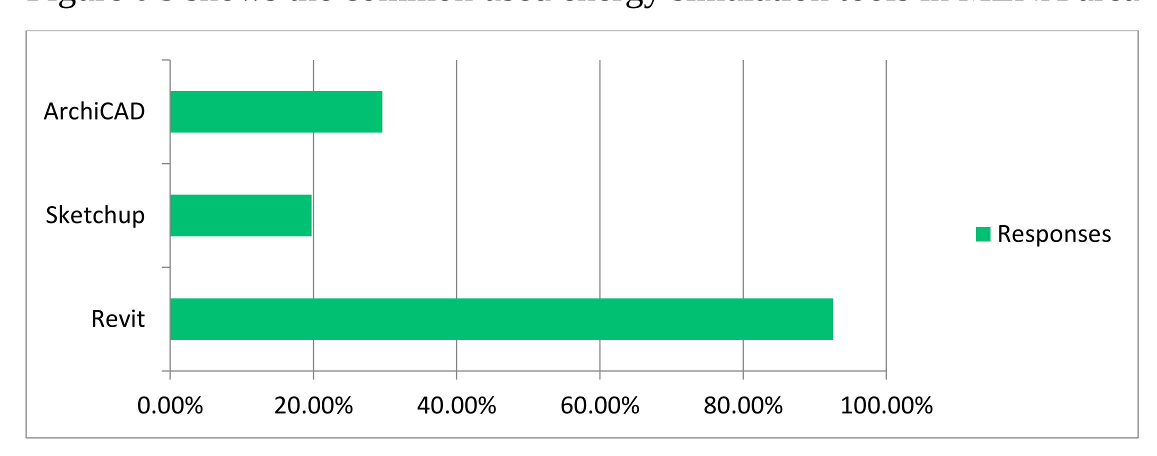


Figure 6-2: Common used modeling software in MENA area

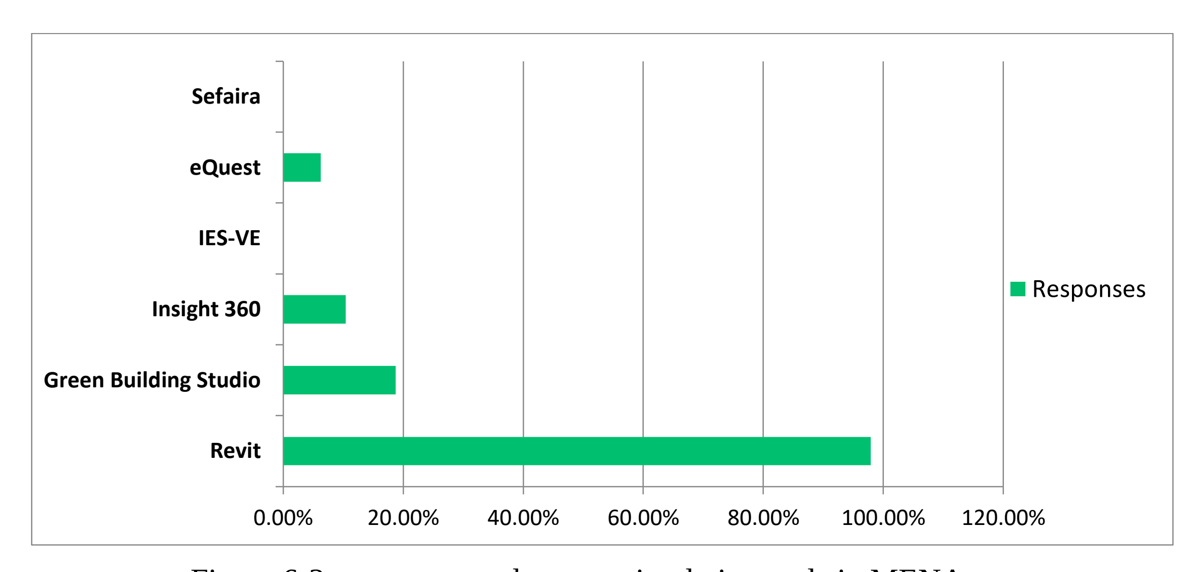


Figure 6-3: common used energy simulation tools in MENA area

6.3 Adopting the Green Building Rating System

Each green building council around the world developed a specific green building rating system in order to fit their regional demands. A lot of them established with intent to produce a global rating system. Based on the questionnaire results, LEED® is the common used rating system for green building certificates. Therefore, the credit categories system of LEED v4 is adopted for step-by-step workflow study. The following are the major reasons of selecting LEED v4, 2014:

- The research conducted a questionnaire asking international and regional firms in many countries about the rating system they are using. There are 70 respondents participated in the survey, 62 respondents said they are using LEED which means 88.57% of total respondents, Figure 6-4 shows the result of survey about the most common rating system used.
- The availability and easiness of accessibility of all required information related to LEED v4, 2014 credit category using USGBC web site.
- Widely use of LEED v4, 2014 rating system around the world.

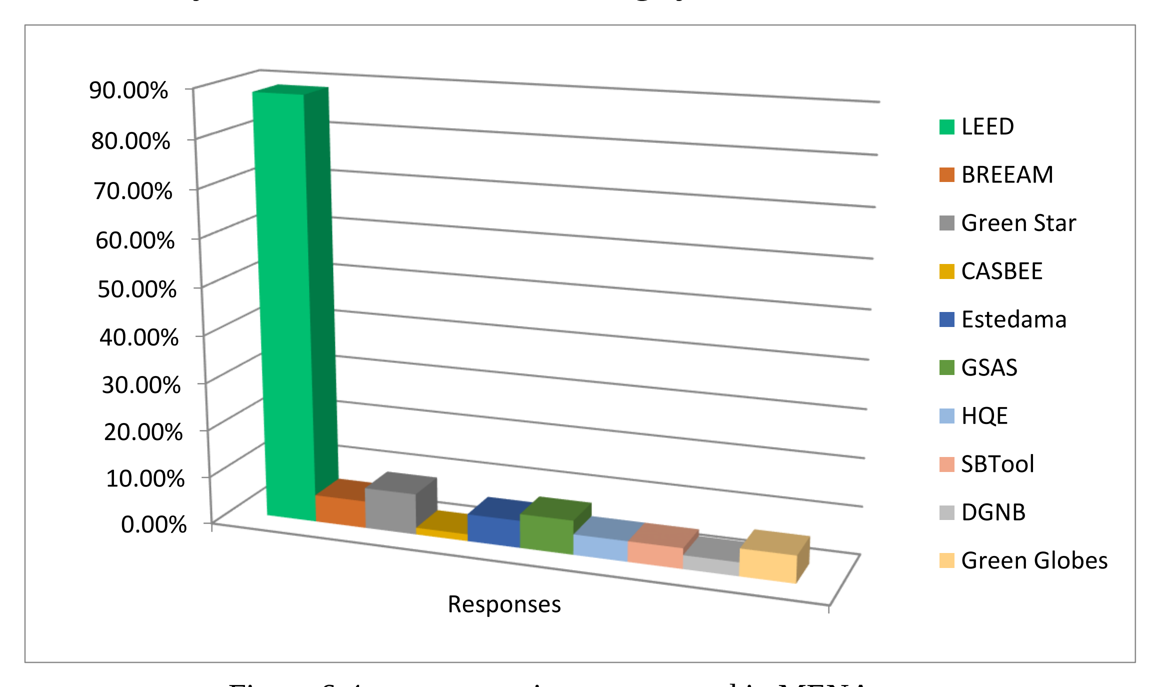


Figure 6-4: common rating system used in MENA area

CHAPTER 7

Case Study

A case study carried out to demonstrate the information modeling process of a project pursue to achieve LEED® v4 certification. The selected case study is a "4 Stars Hotel" project located at Northern Province of Saudi Arabia with. The project land has an area 4230 m^2, and the building consists of (100 hotel rooms) and other hotel service facilities distributed among seven floors. Each floor has approximate area of 1825 m^2, for a total gross area of 12600 m^2 with a building perimeter of 180 m and project boundary 376 m. Pre-designed checklist applied on the 3D model to measure the potential green building points could be achieved under LEED® v4 credit categories. The proposed methodology has been applied to verify the capabilities of the model and examine its performance among the total potential scores of different credit categories. Table 7-1 shows the design process and BIM tools interoperability in sequence during LOD 100&200 applied on the case study and, Table 7-2 shows the remaining design process & interoperability steps in LOD 300&400.The research followed the best practices advised by Autodesk® as a guide through modeling and simulation processes described in the following pages. Table 7-4 describes the analysis of required information for all credit categories according to LEED v4 for (NC). In addition, Table 7-5 describes the analysis of required information according to the Location and Transportation credit category (LT). Table 7-6 describes the analysis of required information according to the Sustainable Sites (SS). Table 7-7 describes the analysis of required information according to the Water Efficiency (WE). Table 7-8 describes the analysis of required information according to the Energy and Atmosphere (EA). Table 7-9

describes the analysis of required information according to the Materials and Resources (MR). Table 7-10 describes the analysis of required information according to the Indoor Environmental Quality credit category. The case study results show that, the total potential scores can be assessed using the proposed integration method is 70 points out of the total 100 scores.

Table 7-1: Design process & interoperability steps in LOD 100&200

I.	**LOD 100**			
No	**Step and Requirement**	**Recommended Software**	**Responsible**	**Notes**
1.	Open new project file	Autodesk® Revit 2018		
2.	Import the partial district file with (.IFC) or (.rvt) extension	Autodesk® Revit 2018	City Server / Local Authority	*The research considered that the project has been located in well managed area using shared source for City Model which allow design team to import the needed part of 3D-GIS map model (as described in literature review)*
2.	Create a conceptual 3d model for the project	Google maps & AutoCAD® map 3d Autodesk® Revit 2018	Design Team	
3.	Import a map for project surrounding area to Revit file	Google maps & Autodesk® Revit 2018		
4.	Assign project in real geographic location and align the exported map using survey point	Autodesk® Revit 2018		
5.	Create 3d map for 1 Km buffer area around the project location	Autodesk® Revit 2018		
6.	Identify the 3D map objects	Autodesk® Revit 2018		
7.	Program a Revit API Add-in to recognize the identified objects on the 3D map.	Autodesk® Revit 2018	Design Team & API programmer	
8.	Extract required information for LEED credit categories (Location & Transportation, LTc1, LTc2, LTc3, LTc4, LTc5 and, LTc6) (Sustainable Sites, SSc3)	LEED Eval add-in Autodesk® Revit	Design Team	
9	How many points could be achieved?			

Table 7-2: Design process & interoperability steps in LOD 300&400

II.	**LOD 300 & 400**		
No	**Step and Requirement**	**Recommended Software**	**Notes**
10	Develop the 3d model elements for the building and major site components (Parking, shades, walkways, hardscape area, soft scape area, including at least envelope components & materials and specify accurate zoning and spaces	Autodesk® Revit 2018	
11	Assign materials for model envelop	Autodesk® Revit 2018 & use trusted vendor families	LEED requirement were considered in material properties, energy settings and thermal properties
12	Assign rooms, spaces and zoning	Autodesk® Revit 2018	This step is very important for a lot of calculations like; (Cooling & heating, Lighting, and Acoustic calculations)
13	Create energy model	Autodesk® Revit 2018	
14	Run energy simulation	Autodesk® Revit 2018	
15	Check energy simulation results	Autodesk® Revit 2018	
16	Export gbXML file to GBS cloud	Autodesk® Revit 2018	
17	Optimize Energy consumption and estimating Water demand baseline and improving efficiency, Also, try and compare other alternatives. Then, export gbXML file	Green Building Studio®	
18	Re-Import gbXML file in Revit	Autodesk® Revit 2018	
19	Check and optimize energy behavior. Compare project with Architecture203 and Net Zero target.	Insight 360®	
20	Use other BIM tools for more analysis and details	Autodesk® Flow Design, Design Builder, DIAlux evo, IES-VE, eQuest.. and other	
21	Use Revit plug-ins (One click LCA, Elum Tools, EXNO, UL. and other when needed) for related LEED calculations	Autodesk® Revit 2018 Plug-ins/Add-ins	
22	**Extract remaining information related to LEED v4 credit categories**		
23	In parallel with previous steps, complete required information in the proposed Excel sheets.	Proposed Excel Sheet	
24	Excel sheet is pre-programed to calculate the potential LEED v4 point.	Proposed Excel Sheet	

7.1 Energy Analysis steps based on Best Practices

The following modeling process conducted according to Best Practices topics for additional guidelines that are specific to the chosen analysis mode.

7.1.1 Conceptual Masses

7.1.1.1 Review the location

Energy analysis uses assumptions based on the geographic location of the model. In addition to affecting weather information, the location affects the carbon content of the electricity supplied to the project. Before starting an analysis, check the specified location in the Energy Settings dialog to make sure it is appropriate for the model. In the Location dialog, select the appropriate weather station using the Internet Mapping Service option. If you change the model's location or other energy settings, when run a new energy simulation, select Create New for the Green Building Studio Project in the Run Energy Simulation dialog. This setting ensures that the updated location and other settings are used in the analysis (Autodesk. 2018). Figure 7-1 shows project geographic location and nearest weather station using Revit 2018.

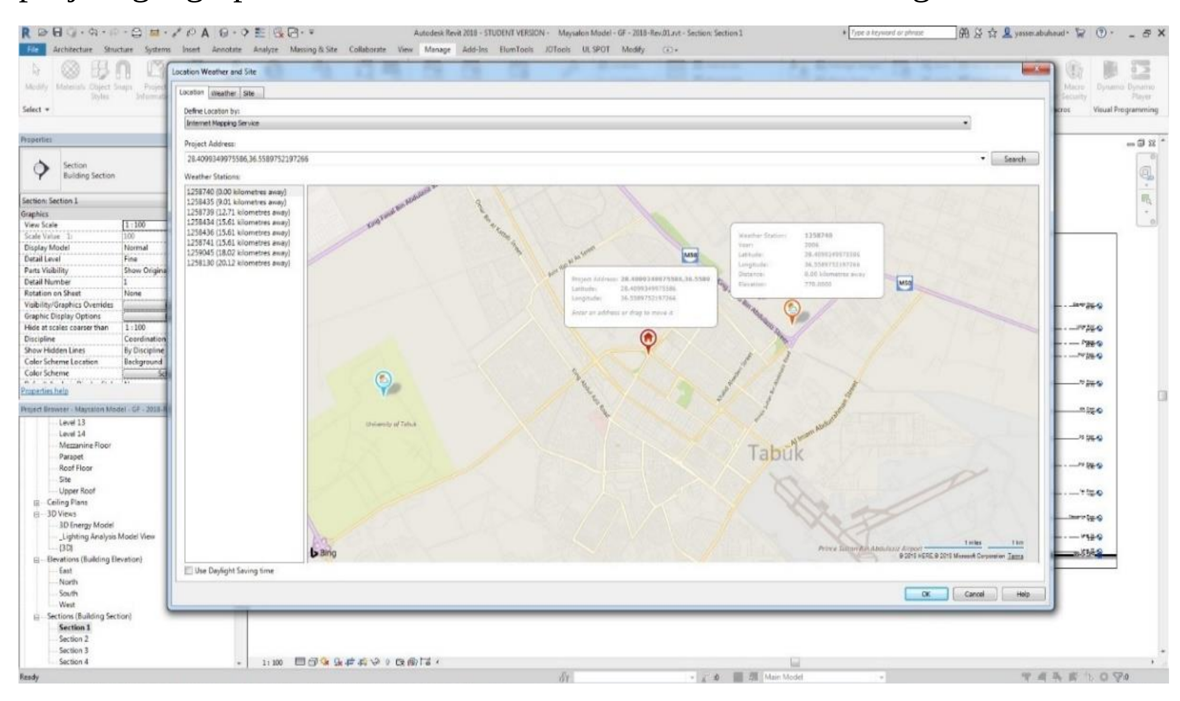


Figure 7-1: Assign project location and nearest weather station in Autodesk® Revit 2018

7.1.2 Keep it Simple

Start with a simple model to study massing and orientation on the project site. Use conceptual energy analysis during the early design phase to ensure that energy use and natural resources are considered during the design selection process. Greater geometric complexity does not necessarily result in greater accuracy during analysis. Model only major spaces and combine smaller spaces that represent key requirements of the project. You do not need to define minor spaces like rest rooms, closets, or stairwells. By partitioning the space into more parts than necessary, you may introduce errors and slow the simulation without significantly improving the accuracy of the results (Autodesk. 2018).

7.1.3 Create masses or walls to define shading objects

If nearby buildings or structures will shade the building, those building may have modeled to ensure that the energy analysis incorporates their effects on the project building. For the energy analysis, design team can hide or omit any buildings that do not directly shade the model. Note: the trees shades ignored during the energy analysis. To create a shading object that represents a nearby structure, create a simple mass form that approximates the size and position of the other building. Do not apply mass floors to this mass. When a mass does not have mass floors, Revit considers it a shading object for the purpose of energy analysis. As an alternative, you can represent a nearby structure with a freestanding wall. To ensure that the energy analysis does not treat the wall as an additional space, clear the Room Bounding parameter for these walls. Then in the Energy Settings dialog, set Mode to Use Building Elements or Use Conceptual Masses and Building Elements (Autodesk. 2018). Figure 7-2 shows Shades from nearby buildings Revit 2018.

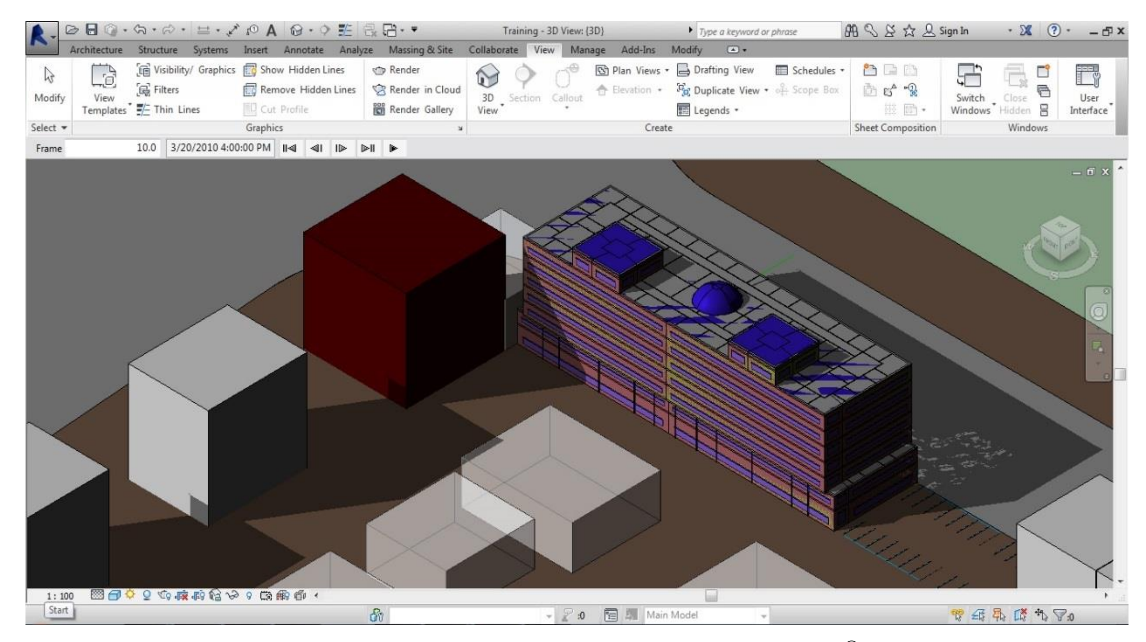


Figure 7-2: Shades from nearby buildings in Autodesk® Revit 2018

7.1.4 Use Thermal Zoning

Thermal zoning can help to improve the accuracy of energy simulations. Automatic thermal zoning uses advanced algorithms to divide the geometry into thermal zones without additional modeling. You can also create custom thermal zones to reflect specific design parameters (Autodesk. 2018). Figure 7-3shows Automatic thermal zoning using Revit® 2018.

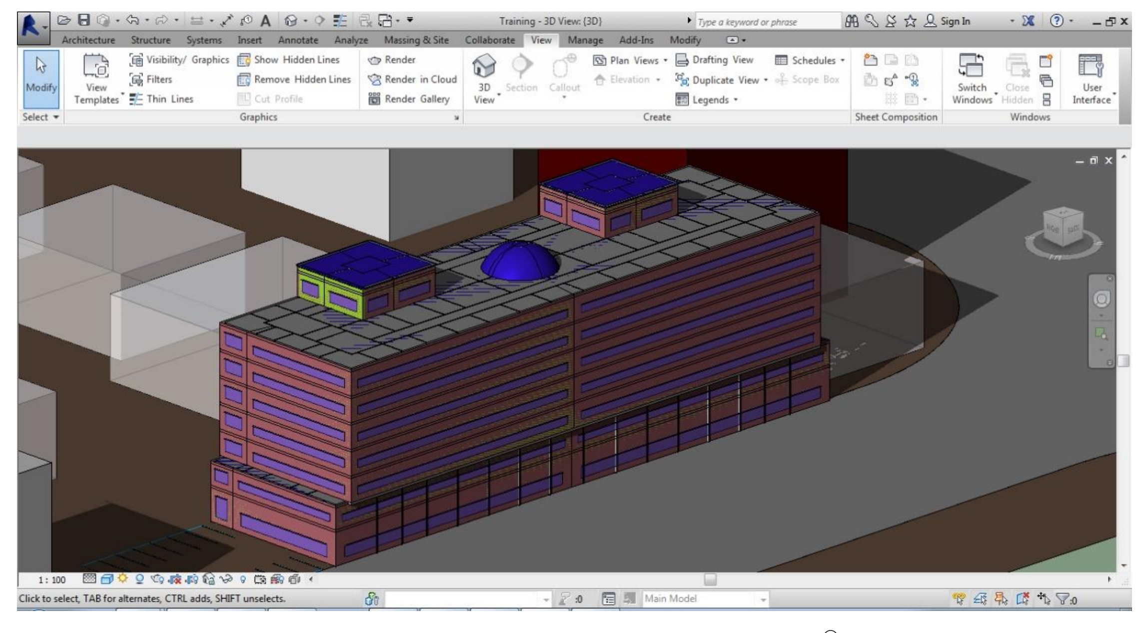


Figure 7-3: Automatic thermal zoning in Autodesk® Revit 2018

7.1.5 Review conceptual types for thermal properties

Before running an analysis, review the conceptual types specified using the Advanced Energy Settings dialog. Adjust them as appropriate for the model. The default conceptual types do not necessarily match the climate conditions for the project location. For example, the default for Mass Exterior Wall is "Lightweight Construction – mild climate," even if the project location is a cold climate like Moscow (Autodesk. 2018). Figure 7-4 shows conceptual types for thermal properties using Revit 2018.

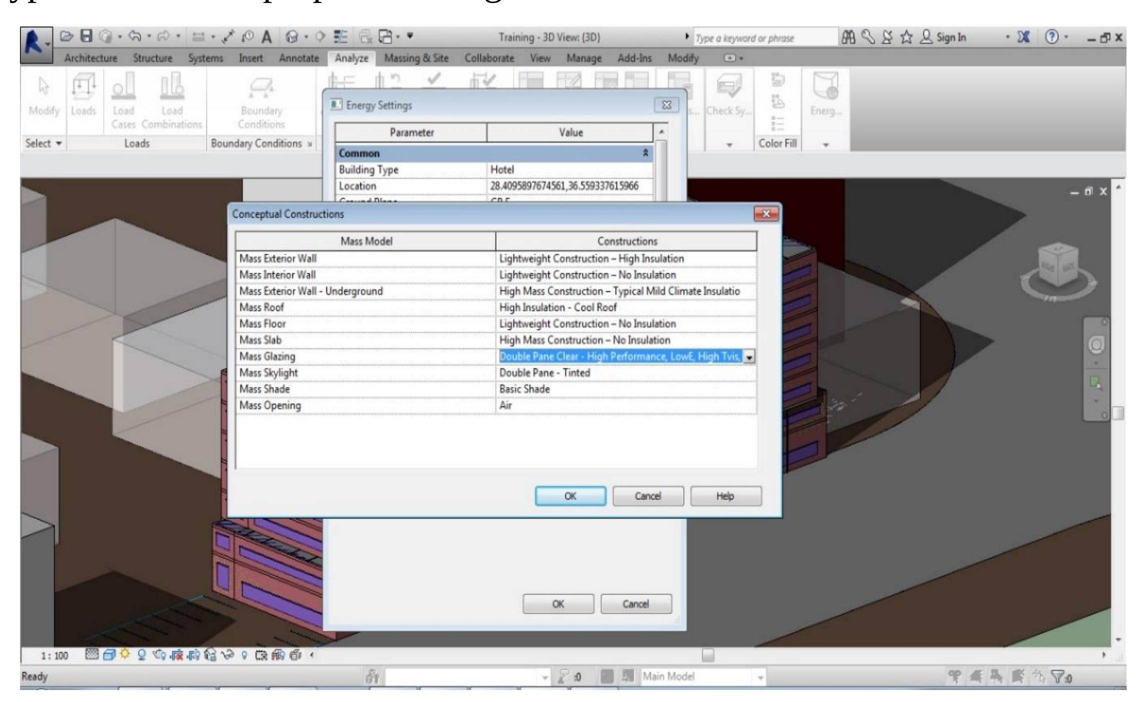


Figure 7-4: conceptual types for thermal properties in Autodesk® Revit 2018

7.1.6 Review the energy model before submitting it for analysis

When thinking the model is ready for energy analysis, click Create Energy Model. This tool generates the energy analytical model and allows design team to examine it before the analysis begins. Pan, zoom, and rotate a 3D view of the energy model to examine it closely. Look for unexpected geometry and areas that are not enclosed. Correct these issues before submitting the model for analysis (Autodesk. 2018).

7.1.7 Analyze 3D views

Perform energy analysis using a 3D view in the drawing area. Revit simulates only the masses that display in the 3D view. When the simulation is complete, the Energy Analysis Result section of the Results and Compare dialog shows the mass that was simulated (Autodesk. 2018).

7.1.8 Align surfaces

During simulation, the type of surface affects automatic modeling (such as the presence of glazing and sky lighting) and impacts simulation results, including heat loss or gain. Misaligned surfaces can lead to simulation errors, such as interior wall surfaces analyzed as exterior wall surfaces or floor surfaces analyzed as roofs. To avoid these simulation errors, model masses accurately so that coincident surfaces align properly (Autodesk. 2018).

7.1.9 Simplify a complex model

Simulation may fail on models with curved surfaces or complex shapes because these surfaces are faceted by the system. Automatic zoning (defined using a core offset and divided perimeters) further increases the complexity of the model. If simulation fails, modify the model by simplifying or removing curves. In a complex model, replace the use of automatic zones with custom zones to simplify the core (Autodesk. 2018).

During conceptual energy analysis, Revit can simulate the following maximum numbers of surfaces and spaces:

- Spaces/rooms: 9999
- Exterior walls: 64,000
- Interior walls: 64,000
- Windows: 64,000
- Doors: 4096
- Shades: 10,000

7.1.10 Experiment

Try using different simple forms to determine which changes have the largest impact on energy consumption or allow the most potential energy generation. Certain building parameters influence energy consumption more (or less) than you might expect due to the building type and location. For example, experiment by running an analysis on a model that uses a large amount of high performing glass. Then run a second analysis on a model that uses low performing glass. Compare the results to see whether modifying the glass has a significant impact on energy consumption for the building type and location. The energy consumption of buildings with high occupancy rates or equipment densities (such as assembly buildings, data centers, convention centers, and theatres) often depends on assumed hours of operation and intensity of operation. For these building types, it is important to determine the simulation parameters that are the primary drivers of energy consumption. Study and optimize orientation, glazing type and quantity, and shell construction. Remember that the Use Conceptual Masses mode for the Run Energy Simulation tool is designed to provide energy analysis on conceptual models. It is not intended to provide results that are equivalent to energy analysis on detailed designs (Autodesk. 2018).

7.1.11 Consider using design options

Use design options to explore alternative forms quickly and easily. Then analyze each option and compare the results. The Run Energy Simulation tool analyzes the design option that is currently visible in the 3D view.

Note: Design options are supported for energy analysis using conceptual masses only. Design options are not supported for energy analysis using building elements (Autodesk. 2018).

7.1.12 Review surface assignments

Assign different constructions or parameters to individual mass floors, walls, windows, roofs, and skylights in the model. Parameters defined for individual faces override the project-wide settings defined in the Energy Settings dialog and the Advanced Energy Settings dialog. For example, to reduce the amount of glazing on the south face of the building (Autodesk. 2018):

1. Click Massing & Site tab ➤ Conceptual Mass panel ➤ Show Mass Surface Types.
2. In the drawing area, place the cursor at the edge of the Mass Exterior Wall surface to modify, press Tab until the surface is highlighted (watch the status bar), and click the surface to select it.
3. On the Properties palette, under Energy Model, for Values, select <By Surface>.
4. For Target Percentage Glazing, specify a lower percentage to reduce the glazing, or enter 0 (zero) to eliminate it.

7.1.13 Review space assignments for zones

If you do not want to use project-wide defaults for all zones, assign specific zone/space details to individual zones in the mass model, as follows (Autodesk. 2018):

1. Click Massing & Site tab ➤ Conceptual Mass panel ➤ Show Mass Zones and Shades.
2. Select a zone.
3. On the Properties palette, in the Energy Analysis section, for Space Type, select the desired type.

7.1.14 Use meaningful names for analyses

When you start a simulation (an analysis), assign a concise, meaningful name so you can differentiate among simulations that use different forms and building parameters (Autodesk. 2018).

7.2 Best Practices using Project Elements

When performing energy analysis using building elements, use the following guidelines:

7.2.1 Review room-bounding elements

Before generating the energy model, check the Room Bounding parameter of building elements. Make sure the parameter is enabled for elements that should be used to define rooms and spaces in the energy model (Autodesk. 2018). Figure 7-5 shows a 3D view of Maisalon Hotel modeled by Autodesk® Revit 2018. Figure 7-6 show an example of solar study. Figure 7-7 shows spaces color schema, while Figure 7-8 show the identified space in section view.

7.2.2 Verify that the geometry is closed

Review the building model and verify that the building geometry is reasonably closed. Holes through roofs and floors will compromise the energy model, giving unexpected results in the energy analysis. The energy model does not need to be completely enclosed to generate valid energy analysis results. Use the Analytical Space Resolution parameter on the Energy Settings dialog to control the size of the largest allowable gap for successful energy analysis. If you see analytical shades in unexpected locations of the energy model, some parts of the building model are not properly enclosed. Examine those areas to locate leaks (unenclosed geometry) and adjust the building elements to close them (Autodesk. 2018).

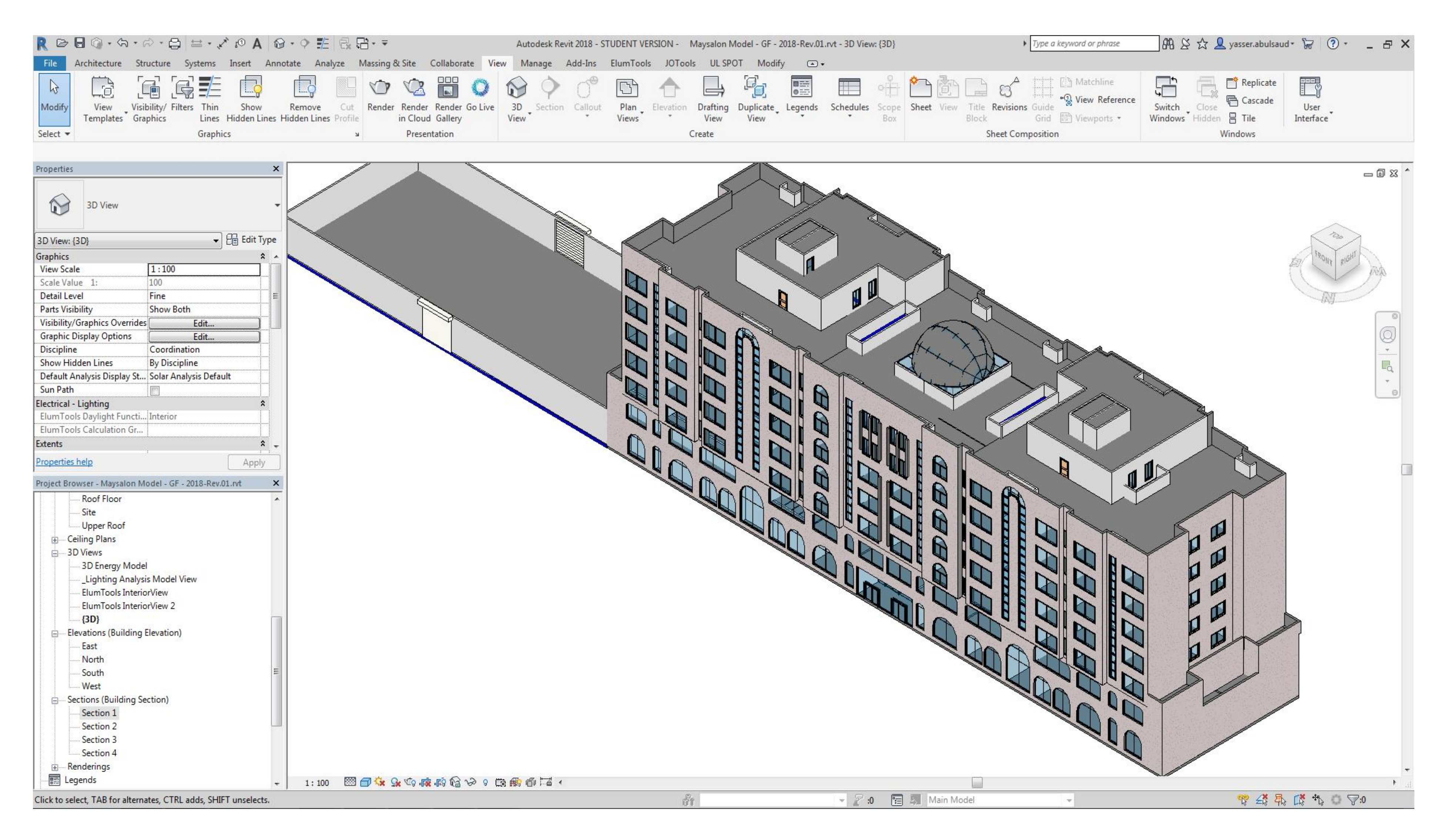


Figure 7-5: Case study- Maisalon Hotel Model (3D view)

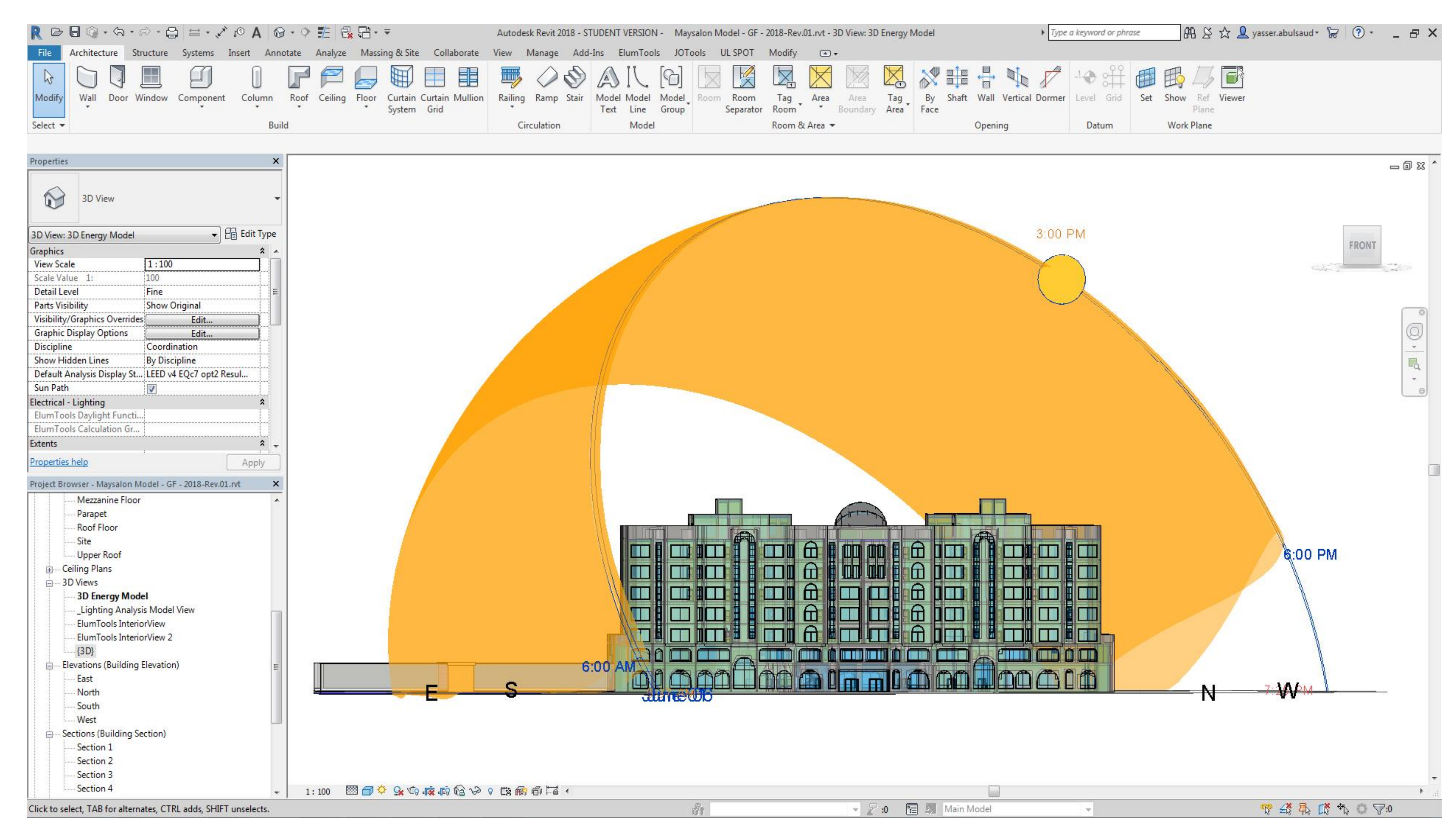


Figure 7-6: Case study- Multi day solar study in Revit 2018

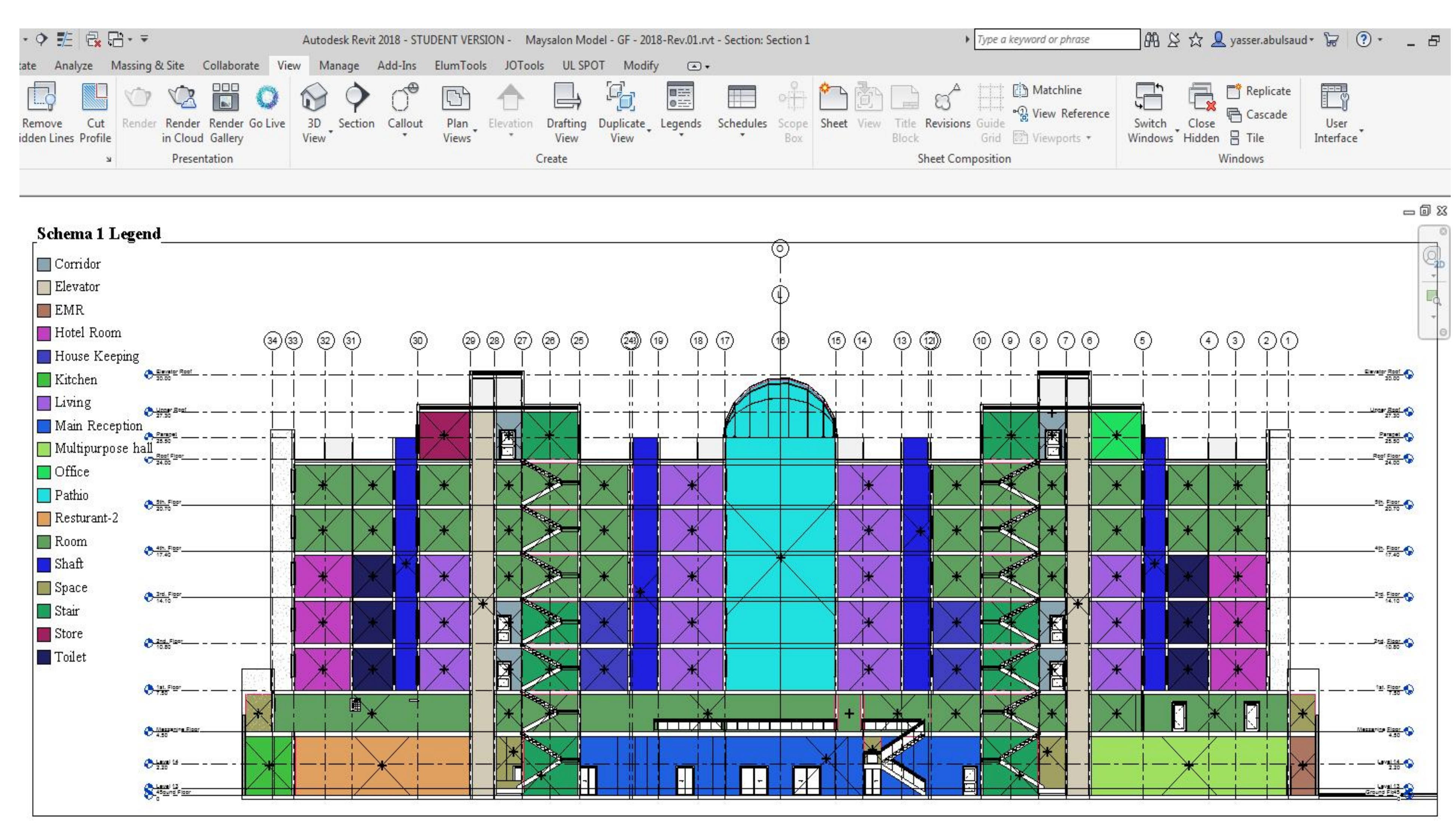


Figure 7-7: Case study- Spaces color scheme in Revit 2018

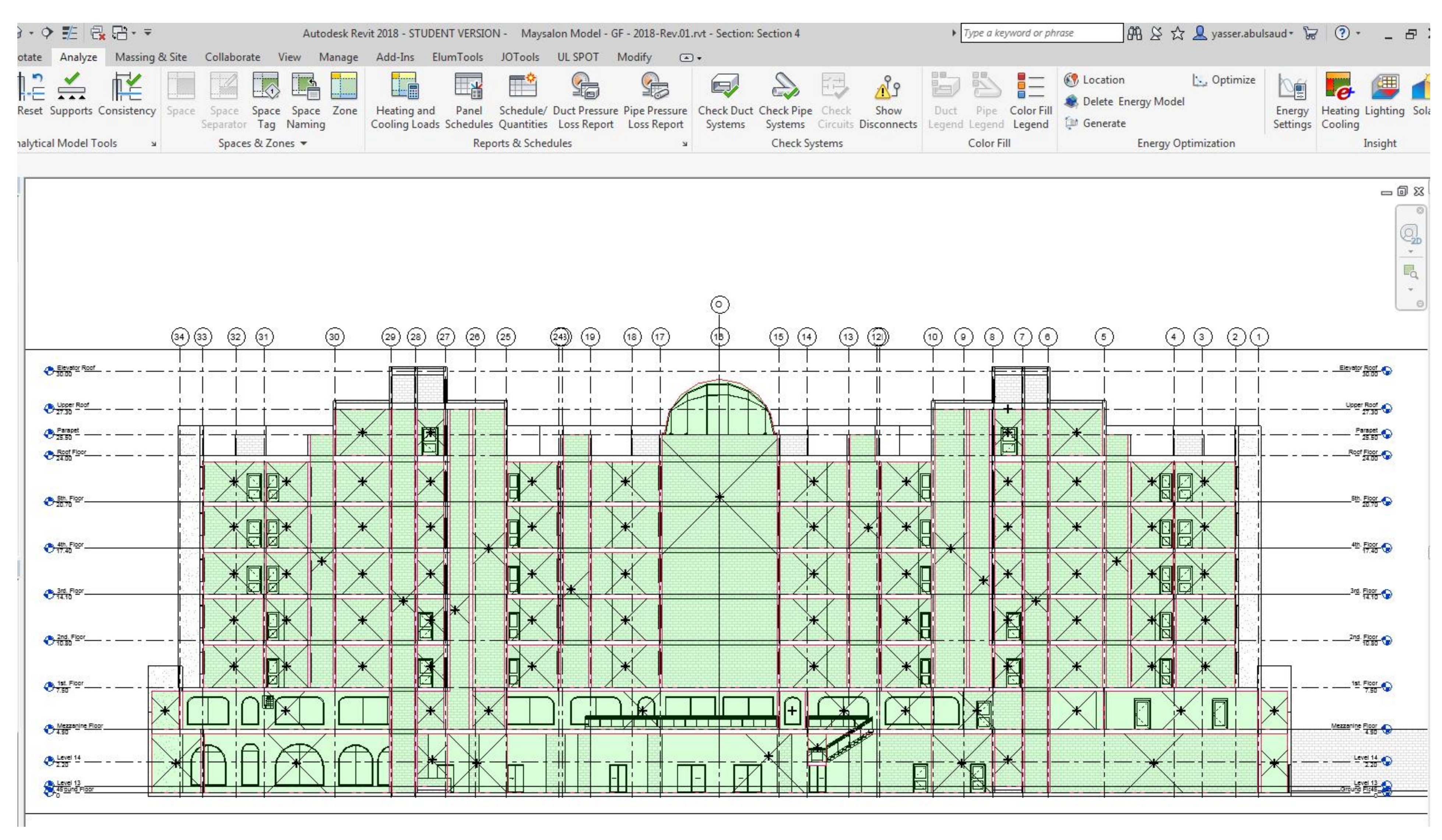


Figure 7-8: Case study- Spaces Identification in Revit

7.2.3 Review analytical spaces and surfaces

Use the Create Energy Model tool to generate the energy model before submitting it for analysis. Review the analytical spaces and analytical surfaces in the energy model. Make sure that the surface types assigned to analytical surfaces are appropriate. Check the volume of analytical spaces to make sure they are sized appropriately (Autodesk. 2018).

7.2.4 Experiment with resolution settings

In the Energy Settings dialog, adjust the values for Analytical Space Resolution and Analytical Surface Resolution. Smaller values may result in a more accurate energy model, but they can cause the energy analysis to take longer to complete. By experimenting with these settings, you can determine the best resolution values that provide sufficient accuracy without undue processing time for energy analysis (Autodesk. 2018).

7.3 Best Practices: Sky-lighting

For 100% daylighting from traditional skylights, approximately 5% of the roof area should be skylights. However, the benefits of daylighting must be weighed against the unwanted effects of heat gain/loss through the skylights. The skylight specifications depend on climate. In all climates, use skylights with a high visible light transmittance (Tvis or VLT). Hot climates should have a low Solar Heat Gain Coefficient (SHGC). Cooler climates should have low U-value. Tubular skylights require a lower skylight-to-roof ratio (SRR) than traditional skylights, approximately 1-2%. When preparing for an energy analysis, use the following parameters in the Advanced Energy Settings dialog:

- Target Percentage Skylights
- Skylight Width and Depth

7.4 Using Revit API add-ins

Revit is the application-programming interface (API). It has enabled the creation of thousands of plug-ins to customize and automate Revit, and

many of the tools we have built for Revit would not be possible without it. There are new tools created every week—tools to increase productivity, to better manage models, and to create stunning client presentations. This thriving ecosystem means that Revit is not limited by what Autodesk can build; it can be customized to suit your needs. API allows for the extraction of other pertinent metrics that would be otherwise difficult to gather but are considered extremely relevant in determining the health of a Revit project (Lance Kirby 2018).

The object diagram of parameters within the Revit API looks like this (Mason 2010):

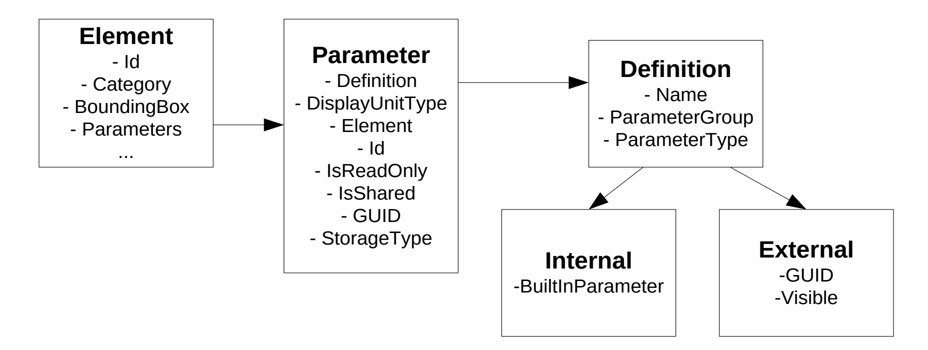


Figure 7-9: Revit API diagram - (Mason 2010)

7.4.1 Using Revit API add-in for LEED credit category Location and Transportation

It is easy to create custom parameters for a project, and for any element or component category in the project. Created parameters display in the Properties palette or Type Properties dialog under the group you define and with the values you define (Autodesk. 2018). The research developed a Revit API to produce a Revit add-in and give it a name (LEED Eval) in order to prove that the required information of LEED v4 is easy to handle using a lot of BIM software. This information could be collected in a specific format like (Excel sheet) to facilitate design team access to the required data just if the team adjust suitable parameters in the conceptual modeling stage. The Figure 7-10 & Figure 7-11 are describing an example for adding new parameter to identify land use. The research used (Add New Parameter)

order in Revit as required inputs needed for further API add-in. Adding new parameter to the Project Information by following the steps below:

1. Go to Manage>
2. Project Parameters>
3. In the new window (Project Parameter) click "Add">
4. The new dialog box (Project Parameter) opens>
5. Type the name of the parameter you want to add
6. Choose what discipline, type and group you want to add
7. Choose what category it would be under
8. Click ok in all the windows.
9. The new parameter will appear in the Properties under the chosen categories
10. Design team can use the appeared box to identify the masses around the project according to divers' uses. (Required for LEED Credit Category Location and transportation LTc4.
11. According to available parameters, API add-in will collect the required information in separate (Text Document) file for each category.
12. Open the Text Document with Microsoft Excel.
13. Connect the imported information with the related cells in proposed Excel sheet of LEED checklist.

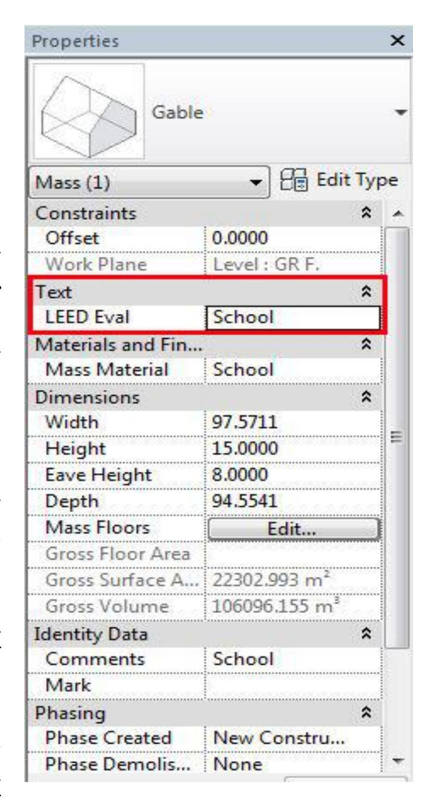


Figure 7-10: Added parameter appear in Mass properties

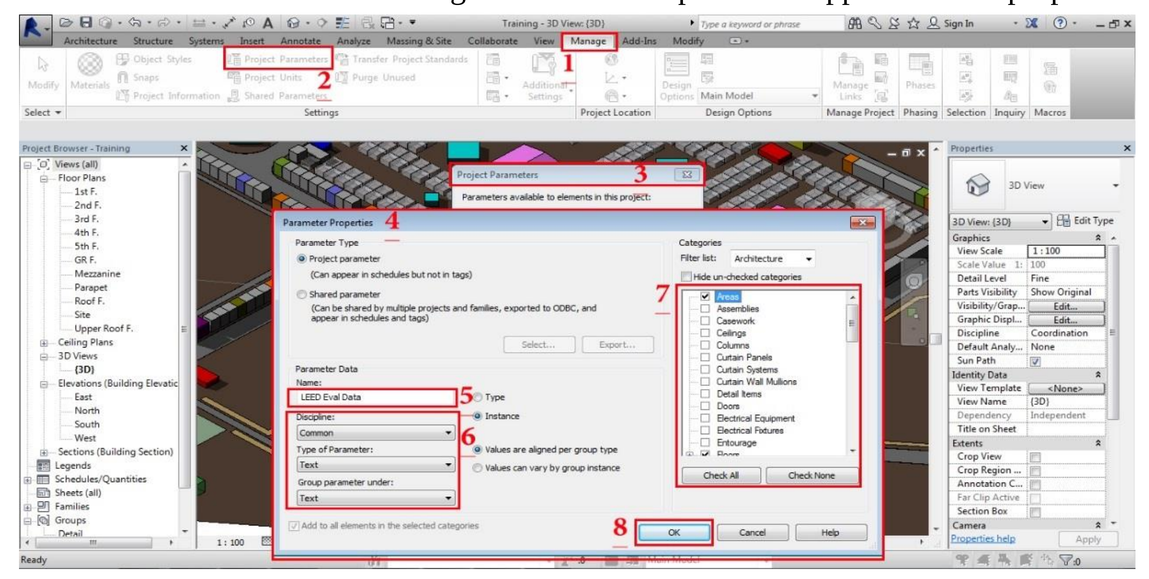


Figure 7-11: Revit Add parameter

In this research, Revit API used to produce an API Add-in based on the new parameter Figure 7-12 show (LEED Eval) add-in interface. The add-in designed to handle the following information:

1. Divers uses and areas around the project location within circular area with any radius determined by user.
2. Area and number of parking spaces within project boundary.
3. Open spaces within project boundary.
4. Residential & Nonresidential area.
5. Floor Area Ratio (FAR).

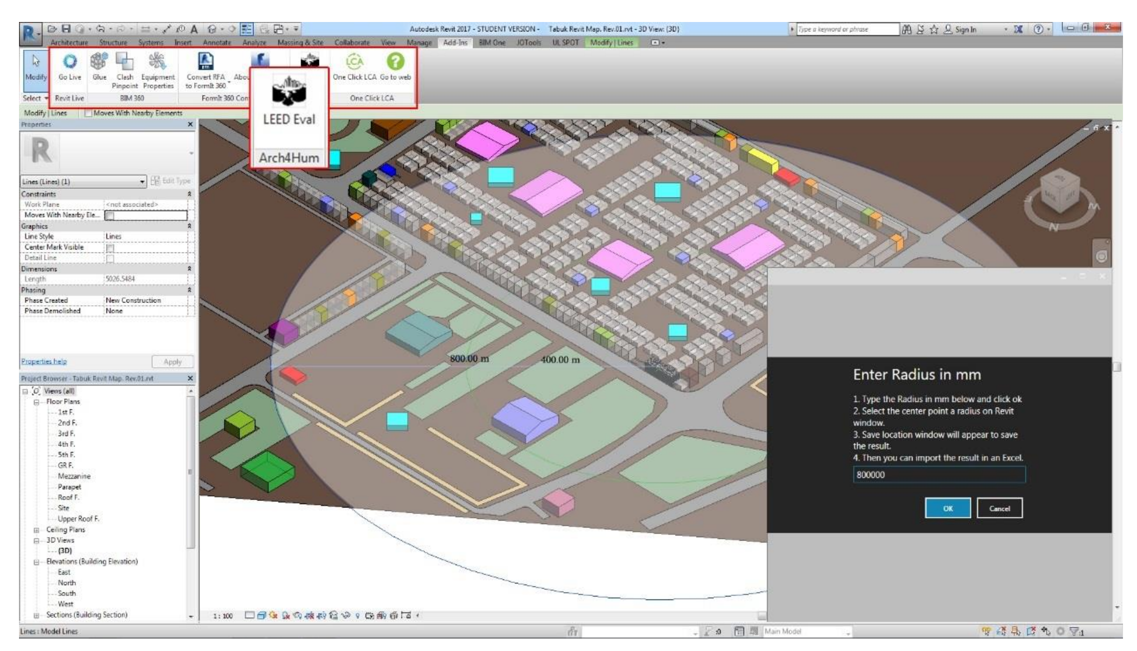


Figure 7-12: Revit API – LEED Eval add-in

7.5 Using Green Building Studio for LEED credits

Autodesk® Green Building Studio (GBS) is a flexible cloud-based service that allows design team to run building performance simulations to optimize energy efficiency and to work toward carbon neutrality earlier in the design process. Autodesk® Green Building Studio is web-based energy analysis software that can help architects and designers perform whole building analysis, optimize energy efficiency, and work toward carbon neutrality earlier in the design process (Autodesk, knowledge network 2014).

GBS uses the DOE-2 simulation engine for calculating the hourly whole building energy usage. GBS allow design team to run energy simulations

using a Vasari or Revit conceptual mass model, a more detailed Revit model, or a gbXML file created by other authoring tools. Energy simulation results can be viewed within the model, or on the GBS website (Autodesk, knowledge network 2014).

7.5.1 Key Features of Green Building Studio

Energy Settings Defaults Allow Reasonable Energy Results with Minimal Inputs. If a parameter has not been defined in the model, GBS uses a default value in order to generate an energy model with the minimum information needed for a simulation. These intelligent values are appropriate to the building type, size, and location. These defaults are primarily based upon the ASHRAE 90.1, ASHRAE 90.2, ASHRAE 62.1 and CBECS data, and vary with building type, location, size, and number of floors (Autodesk, knowledge network 2014).

7.5.2 Quick Effective Energy Efficiency Measures

A typical whole building energy analysis looks at over 50 variations of different parameter alternatives in a building, and that can take considerable time to conduct. GBS tests a variety of building features automatically and, with the Potential Energy Savings chart, provides straightforward guidance on which variations will have the largest impact on energy use. All of these runs are completed in the cloud in about the same amount of time it takes to do one manually (Autodesk, knowledge network 2014).

7.5.3 Tight Integration with Modeling Tools

Green Building Studio's tight integration with the Revit modeling environment makes analysis accessible in the tool most architects and engineers use to design new and retrofitted buildings. New from Autodesk Revit 2014, Revit Energy Analysis became more seamlessly creates valid Energy Analytical Models from detailed architectural models and includes the thermal properties of building elements. Once the simulation is finished, design team can view and compare the energy and carbon results in the

“Results and Compare” window within your model in Revit or Vasari. Based upon the results, design team can revise energy settings and parameters within the model, or within the GBS website, and submit additional analyses for the project to move toward a better and more energy efficient design (Autodesk, knowledge network 2014).

7.5.4 Tools Designed for Simulating Existing Buildings

Design team can synchronize historical weather data and utility billing data for an existing building using the Utility Bill Upload Feature and the Green Button Initiative Feature. This makes it easy to compare historical building performance to simulation results, allowing team to calibrate the model of the existing building towards better evaluate potential energy efficiency measures (Autodesk, knowledge network 2014).

7.5.5 Faster Downstream Analysis with other Engineering Tools

Green Building Studio can export files that can be used by eQuest and other analysis tools. It can be an effective way to get geometry from your Revit building information model into other analysis tools, without having to re-create the geometry in those tools (Autodesk, knowledge network 2014).

7.6 Whole Building Energy Analysis

Moreover, GBS has analyses capabilities, beyond the Whole Building Energy Analysis, using the DOE-2 simulation engine, such as “Carbon Data”, “LEED Daylight”, “Water Use”, “Renewable Energy”, and “Natural Ventilation Potential” to help you move your project toward sustainability (Autodesk, knowledge network 2014). In the Figure 7-13 one of the GBS interface parts (LEED Water Efficiency details and its relation to Net-Zero measures) and Figure 7-14shows annual & monthly data of energy cost calculated by (SR/m2), Figure 7-15 shows annual & monthly data of energy consumption calculated by (kBtu), and Figure 7-16 shows the Energy Use Intensity calculated by (kWh/m2)

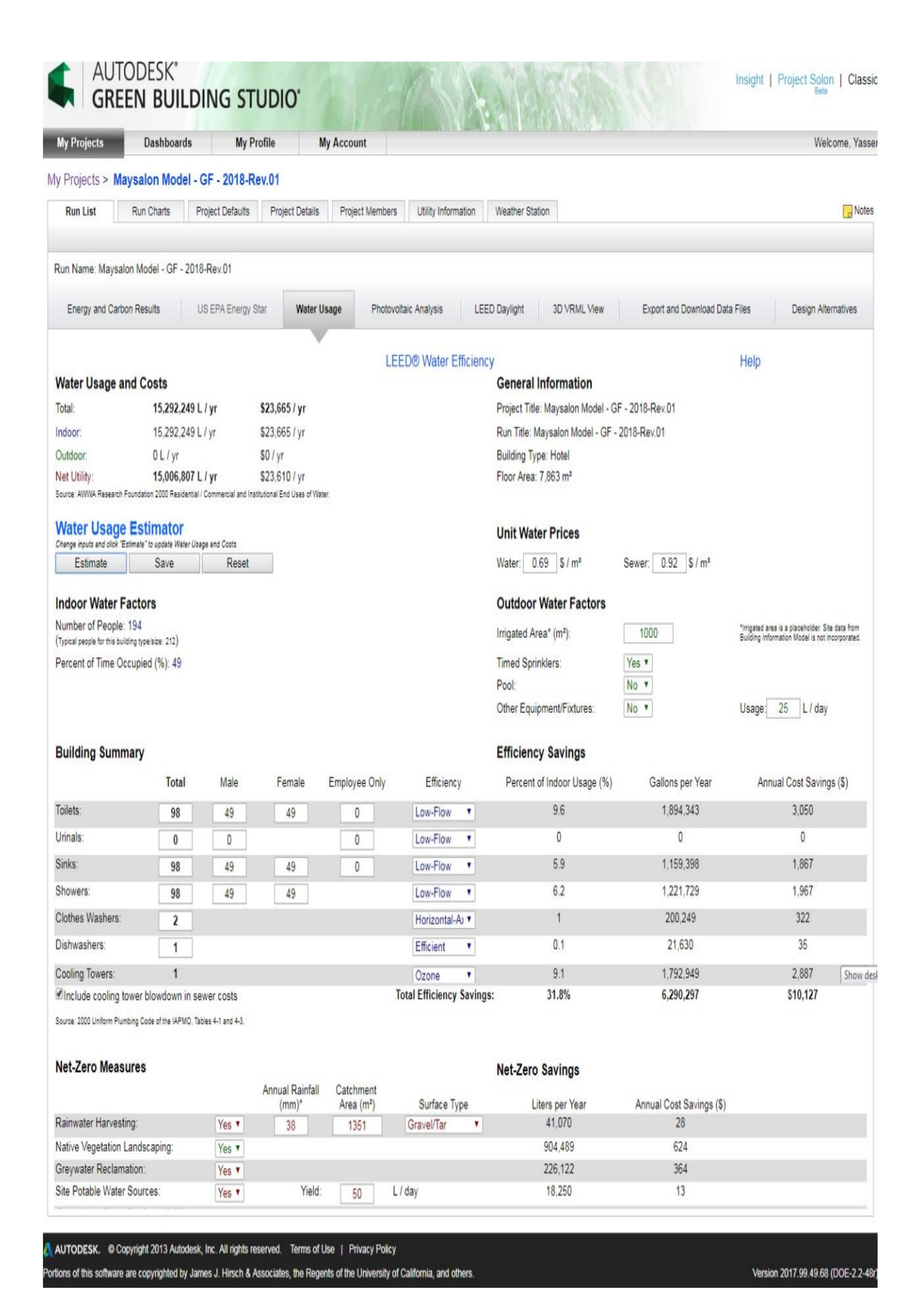


Figure 7-13: Green Building Studio® - Water use estimation

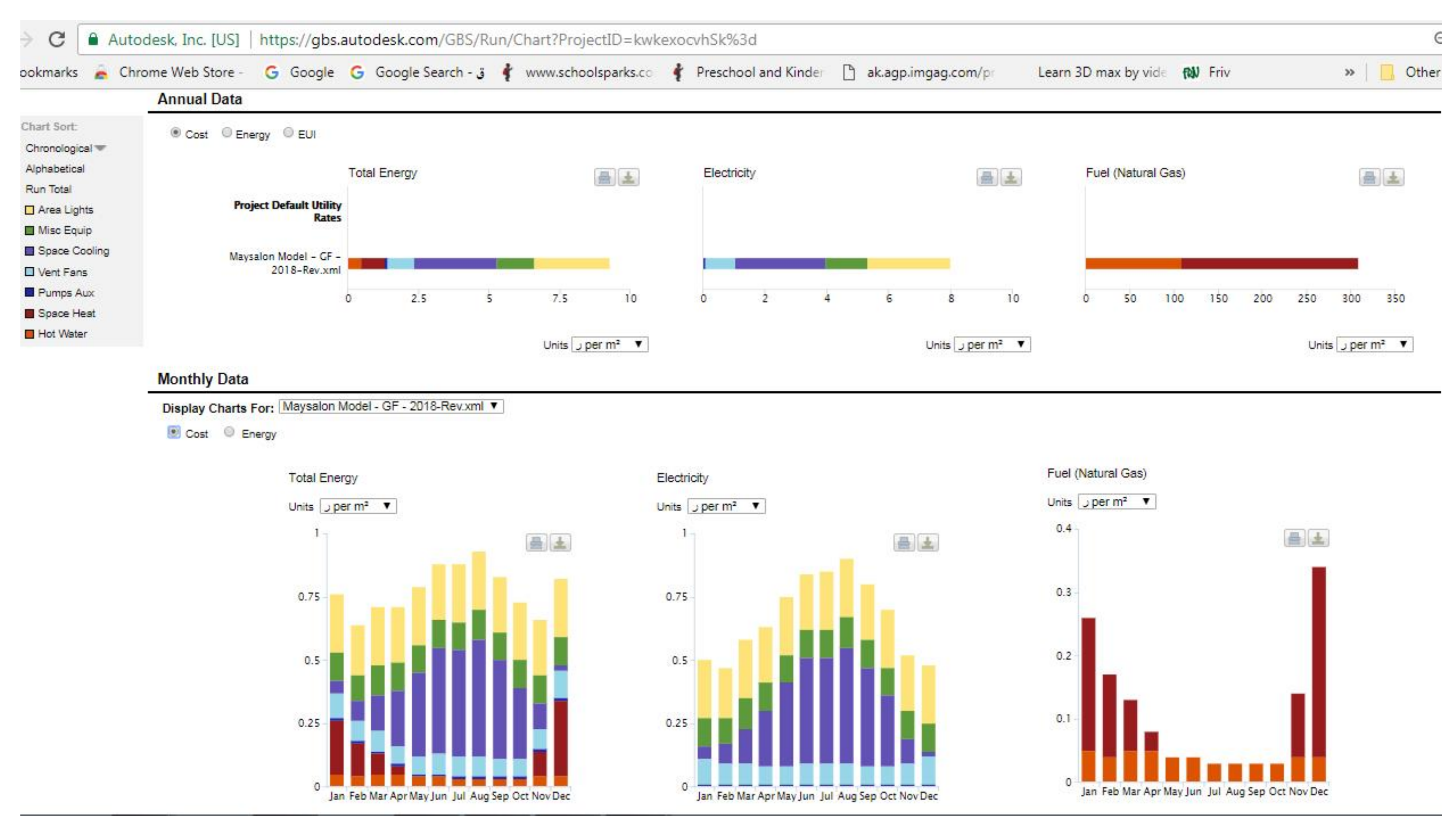


Figure 7-14: Green Building Studio® - Water use estimation

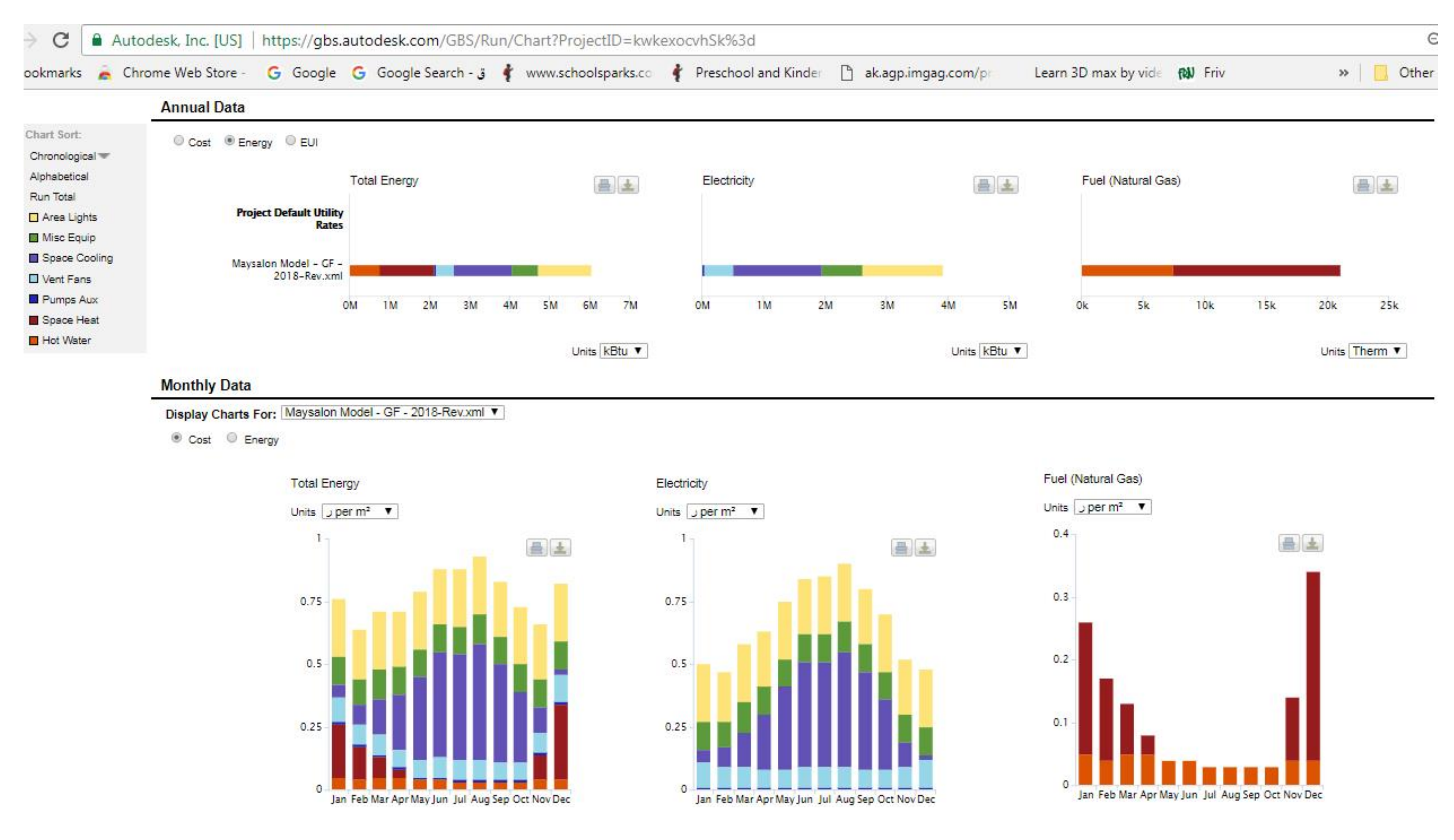


Figure 7-15: Green Building Studio® - Water use estimation

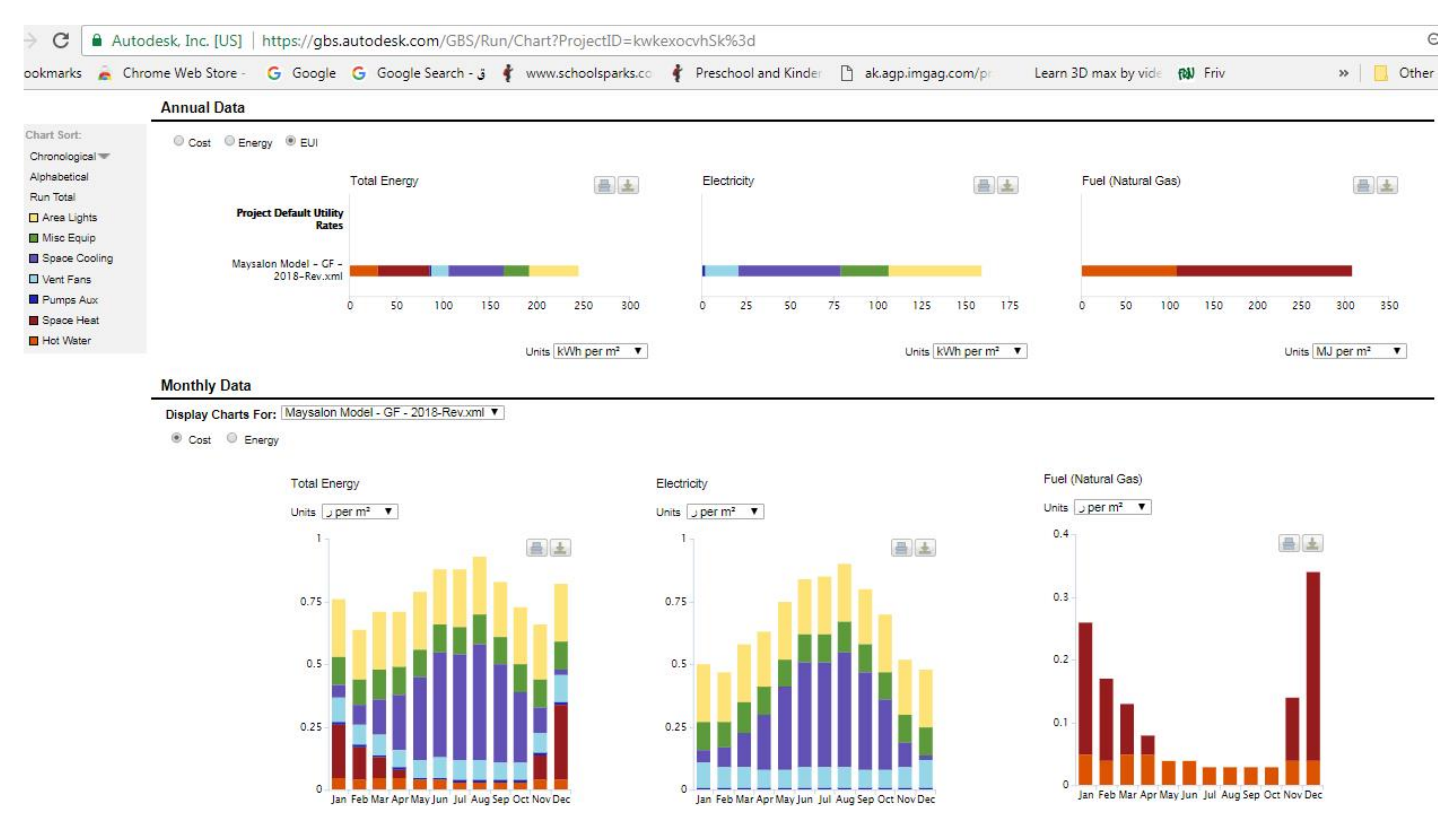


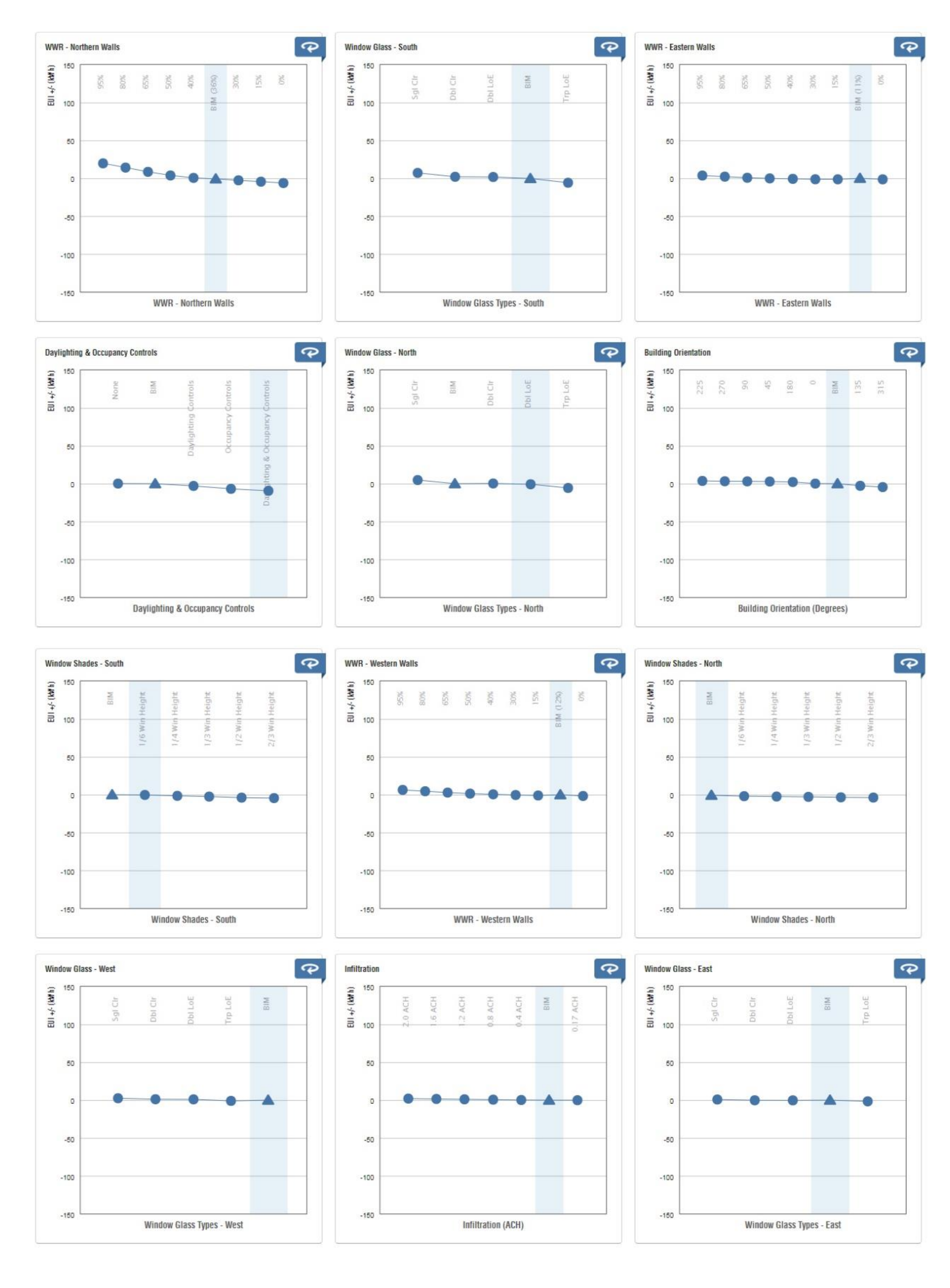
Figure 7-16: Green Building Studio® - Water use estimation

7.7 Using Insight 360 for energy analysis and optimization

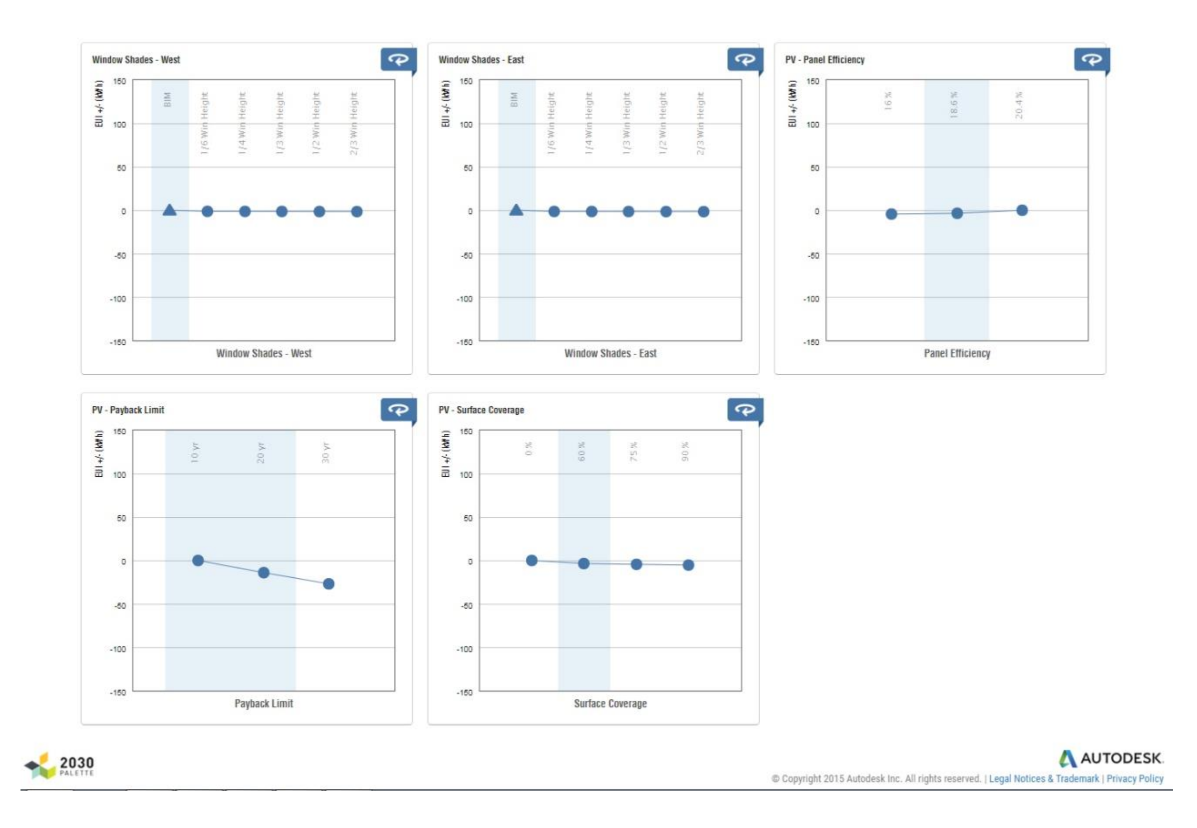
Autodesk at "Greenbuild 2015" has announced insight 360. It is also a cloud-based tool enabling a new way to experience building energy, environmental performance, and the collective actions. That leads to better outcomes throughout all stages of the building lifecycle. Insight 360 empowers architects and integrated teams with centralized access to performance data and advanced analysis engines. Through robust integration with Revit and FormIt 360 and direct access to guidance and recommendations from trusted simulation engines and industry benchmarks, architects can approach the design process with understanding of the elements that lead to better building performance outcomes throughout the building lifecycle. Insight 360 integrates many of the workflows available today such as energy cost range, lighting analysis, solar analysis, and EnergyPlus Cloud as well as expanding upon the current capabilities of these tools to provide a holistic approach to building performance. Easily measure performance against Architecture 2030 and ASHRAE 90.1 benchmarks, making early targeting and feasibility seamless. With millions of potential design scenarios, visualizing the impact of orientation, envelope, WWR, lighting equipment, schedules, HVAC, and even PV has never been easier. Insight 360 allows team to save and compare design scenarios to track performance spanning the building lifecycle in a consistent and cohesive manner. Share the insights with project stakeholders and access all outcomes anywhere (Autodesk 2015). Figure 7-17 shows Insight 360 Interface



Figure 7-17: Insight 360 Interface, Maisalon Hotel analysis



Follow Figure 7-17 Insight 360 Interface, Maisalon Hotel analysis



Follow Figure 7-17 Insight 360 Interface, Maisalon Hotel analysis

7.7.1 Insight Solar Analysis using Revit 2018

Solar studies help designer to visualize the impact of natural light and shadows on the exteriors and interiors of projects. Create solar studies to see how shadows from terrain and surrounding buildings affect a site, or where natural light penetrates a building at specific times of the day and year. By showing the impact of natural light and shadows on your project, solar studies yield valuable information that can help support effective passive solar design.

7.8 Workflow: Solar Studies

Use solar studies to evaluate the impact of natural light and shadows on the project.

1. Create a project.
2. Specify the geographic location of the project.

3. Create a 2D or 3D view that supports the display of shadows. See Create Views for Solar Studies.
4. Turn on the sun path and shadows.
5. Create the desired type of solar study.
6. If you created a Single Day or Multi-Day solar study, view the resulting animation.
7. Save the solar study results.
8. Export the solar study results.

7.8.1 Tips for creating solar studies

- Create solar studies using the sun path or the Sun Settings dialog, or a combination of both.
- Use the Sun Settings dialog to access preset sun positions, shared sun settings, view-specific lighting settings, time intervals, and ground plane settings.
- To produce a series of solar studies, create and open multiple views of a project, and then specify a different solar study period for each view. For example, create separate views for winter solstice, summer solstice, spring equinox, and fall equinox studies. Tile the views to see them all at once.
- You can create solar studies for the same building model in different locations. For example, if the same retail store will be constructed in Los Angeles and London, change the project location, and then export a solar study for each geographic location. Figure 7-18 show the solar and shadow study using Revit 2018.

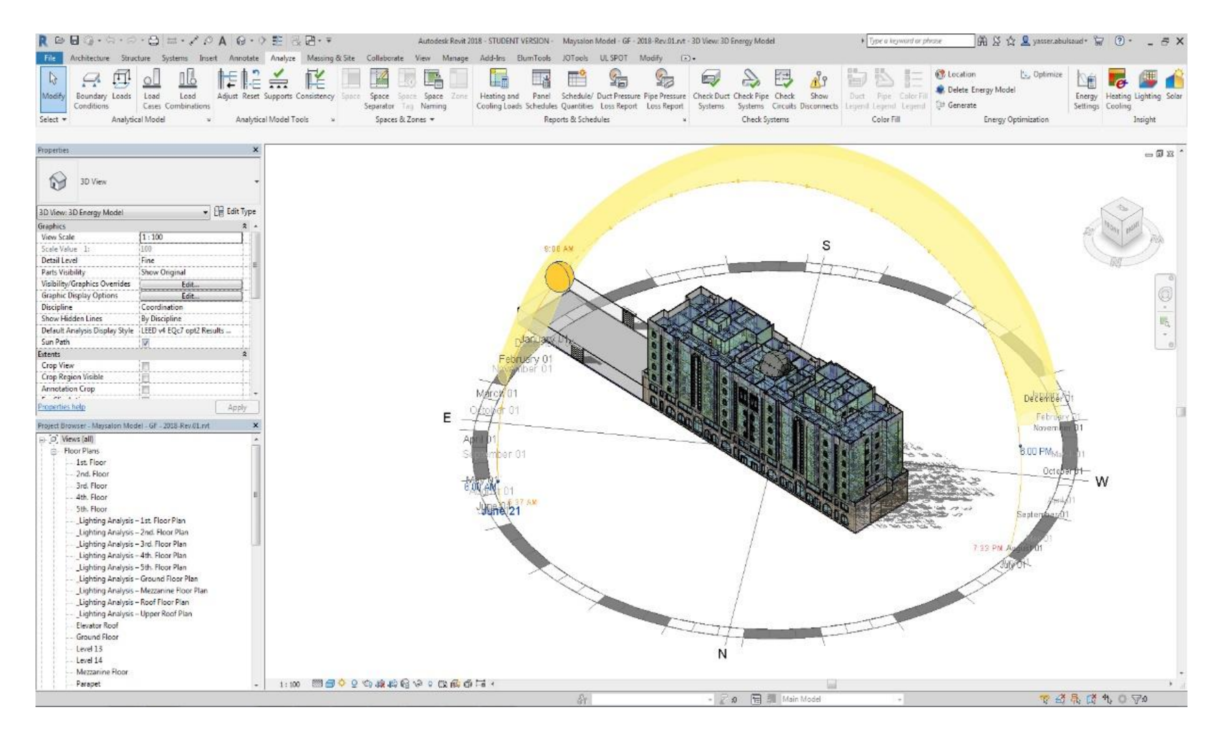


Figure 7-18: Solar and shadow study in Autodesk® Revit 2018

7.9 LEED Daylighting analysis steps using Insight 360

Design team can understand and quantify the amount of the sun's light in your project with daylighting analysis. This can help to create comfortable and beautiful spaces, reduce lighting loads, and reduce cooling loads. When doing daylighting analysis, design team are typically trying to answer some fundamental questions that include:

1. Can we improve the form of the building/room to get more natural light?
2. Can we get enough light for specific tasks?
3. How much can we offset artificial lights with daylight?
4. Is light well distributed and not causing glare?

There are many ways to measure and visualize light and design team may use different tools depending on which question they are trying to answer (Autodesk, Sustainability Workshop 2017).

For Revit 2014, 2015 and 2016 versions, the Light Analysis Revit (LA/R) plug-in uses the Autodesk 360 Rendering cloud service to perform very fast and physically accurate daylighting analyses from within Revit. This plug-in provides LEED IEQc8.1 2009 and LEED v4 EQc7 opt2 results for most models in less than 15 minutes once the analysis is started. The LA/R is specifically designed for architects to be able to use without learning the difference between the Perez or CIE's sky models, direct normal incident or direct horizontal radiation. Just specify if you want to analyze the whole building, single or multiple floors, and kick-off the analysis (Autodesk, Light Analysis for Revit 2015). In further versions 2017 and 2018, the plugin (LEED sDA & ASE studies with Insight Revit 2017) established as built in plugin included to Insight panel. Figure 7-19**Error! Reference source not found.** shows the lighting plugin in Autodesk® Revit 2017 and 2018.

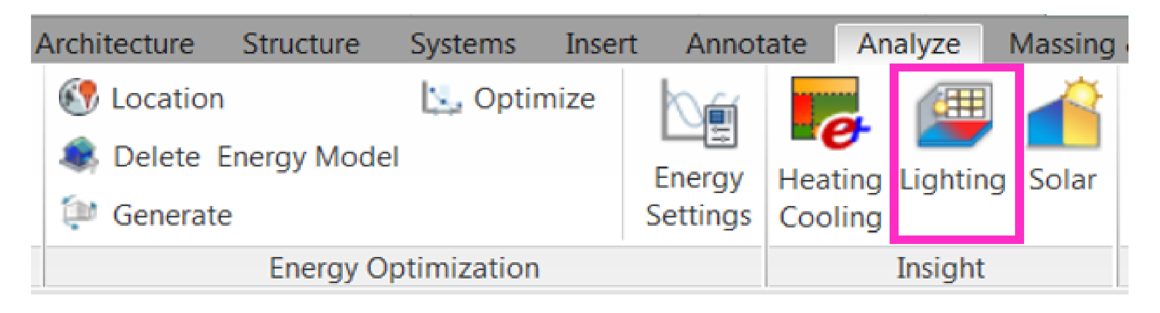


Figure 7-19: Insight panel – lighting plugin in Autodesk® Revit 2017 and 2018

Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) are two important metrics for better understanding annual daylight availability and quality, as well as glare and overheating potential. LEED v4 has adopted both metrics to help designers and engineers determine the impact of daylighting within their building. Follow the steps below to get started with sDA and ASE in Revit with the latest Insight plugin. Also, be sure to use these resources for guidance when setting material properties (Autodesk, LEED sDA & ASE studies. 2016).

The following steps conducted in the research case study as a best practices guidance (Autodesk, LEED sDA & ASE studies. 2016):

1. Open a building element model in Revit and make sure that real location is set. In order to get results for sDA and ASE, user **must have rooms specified in your model**.
2. From the **Analyze** tab, select **Lighting** from within the Insight panel.
3. The first dialog that appears provides resources and best practices for conducting a lighting analysis study. These best practices are not required but will help team achieve more representative results. Select **Continue**.
4. Next, you will have the ability to run a new analysis type or recall previously saved results. Select <Run New Analysis> and then Go. See (Figure 7-20).
5. The Lighting Analysis in the Cloud dialog box will allow you to set your study settings.

There are two daylight autonomy analysis types:

- LEED v4 EQc7 opt1 will automate settings for LEED v4 EQc7 opt1 criteria
- Daylight Autonomy (sDA preview) is a lower cost preview of the full LEED v4 EQc7 opt1 Analysis results will be comparable to the LEED analysis results, however a sampling of typical hours will be used to calculate results. This is a good option for when you want to get a baseline of daylight autonomy values, reduce cloud credit consumption, or test the impact of different design options.

Regardless of which daylight autonomy analysis type you select, the settings will be defined as follows.

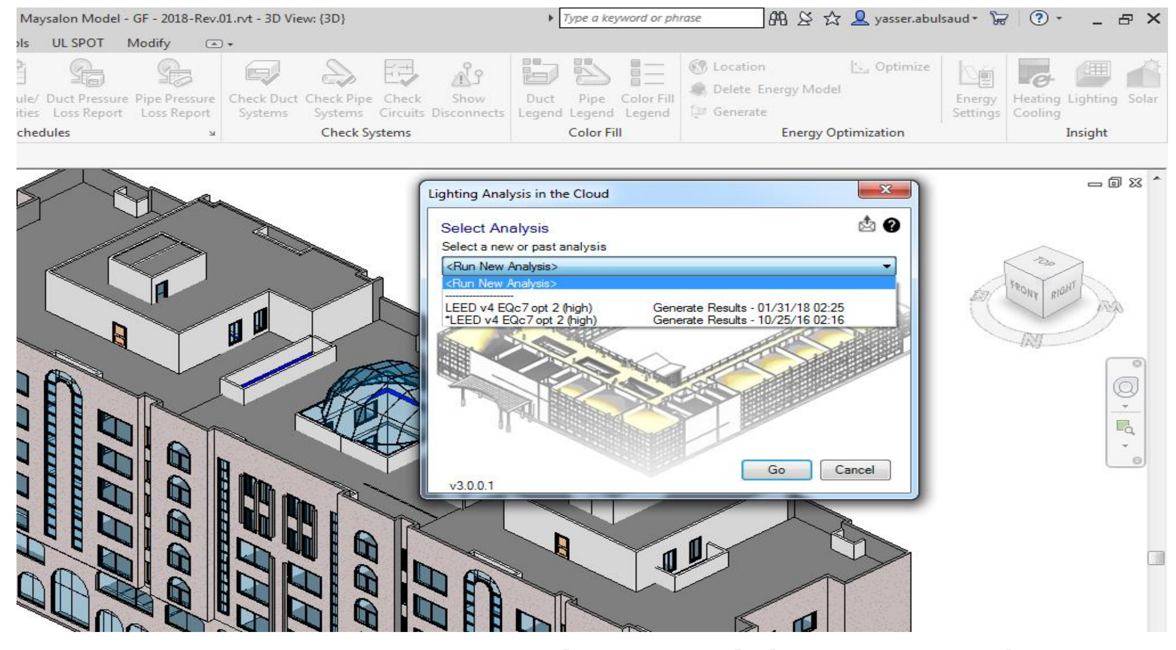


Figure 7-20: Step 4 - Run a new analysis in Autodesk® Revit 2017 and 2018

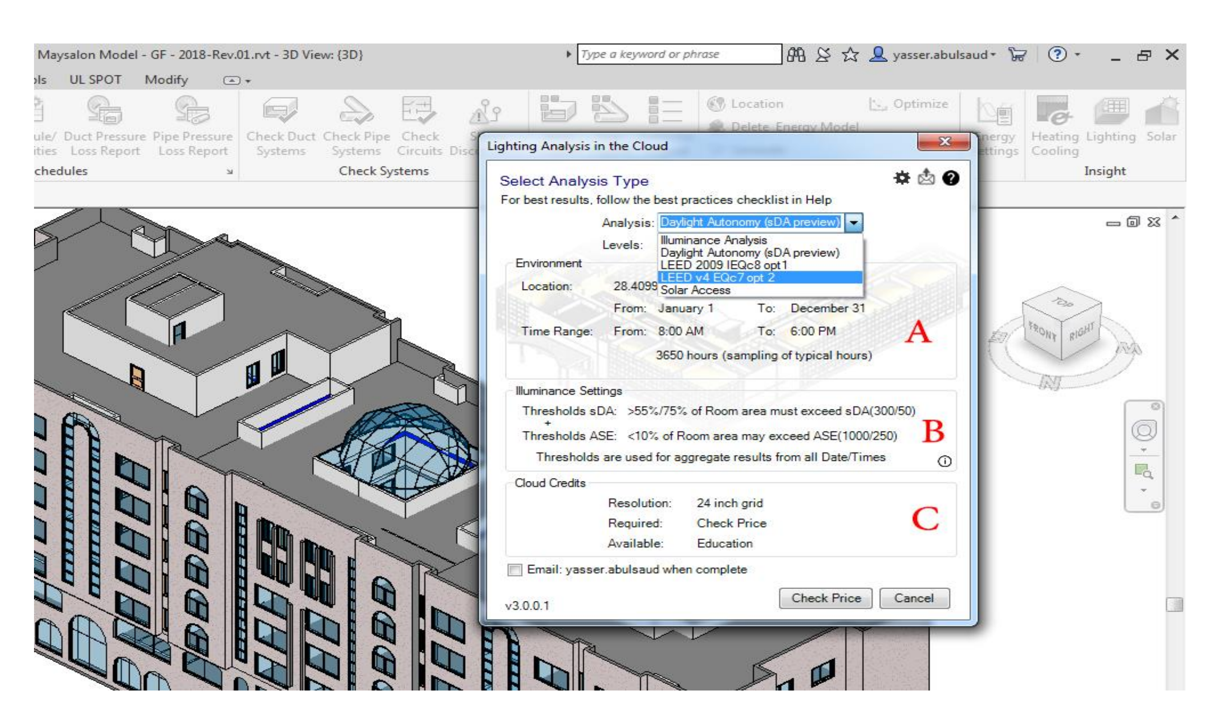


Figure 7-21: Step 5 – Lighting analysis parameters in Autodesk® Revit 2017 and 2018

Figure 7-21 describes the following Lighting analysis parameters:

A. The time range will be automatically set to a full annual simulation, from 8am to 6pm, which will result in 3650 hours for the analysis.

B. Per the LEED requirements, sDA300/50% for at least 55% or 75% regularly occupied floor area is achieved. Additionally, ASE1000/250 of no more than 10% for the occupied floor area that is daylit per sDA300/50%. LEED requires the analysis occur at 30 inches above the finished floor. The analysis plane automatically is generated at this height for LEED studies.

C. sDA and ASE calculations require at 24-inch analysis grid, which is automatically set.

6. Select **Start Analysis** to begin the simulation. Cloud credits will not be charged until the analysis is complete.

Since the sDA and ASE simulation is more intensive than a single point in time, the analysis will cost more Cloud Credits and take more time than a single point in time analysis. Select **Check Price** before submitting the model for analysis to see the required number of cloud credits for the analysis.

7. After selecting **Start Analysis**, the model geometry will be uploaded to the cloud-rendering engine. Do not close the project or Revit during this process.

Once the model is successfully uploaded to the cloud, it is okay to close the project or continue working in Revit. Note that any changes you make to the model geometry or material settings will not be reflected in your analysis results, as the model has already been uploaded for analysis.

8. Revit will notify you once the results are ready. **Accept** or **Decline** the cloud credit charges at this point. It is recommended you also save the project, so you will be able to recall the lighting analysis results after exiting Revit.
9. Open the **_Lighting Analysis Model View** under 3D Views. Note that any "_Lighting …" views are automatically created to easily access

results in plan, 3D, and as a schedule. Analysis results will populate in whatever 3D view is currently active.

10. From the Insight panel select **Lighting** to access your analysis results. This time, select the results for the analysis that has been completed and select **Go**. Figure 7-22 shows that the generated result appears in lighting analysis dialog box within the "select a new or past analysis" drop list.

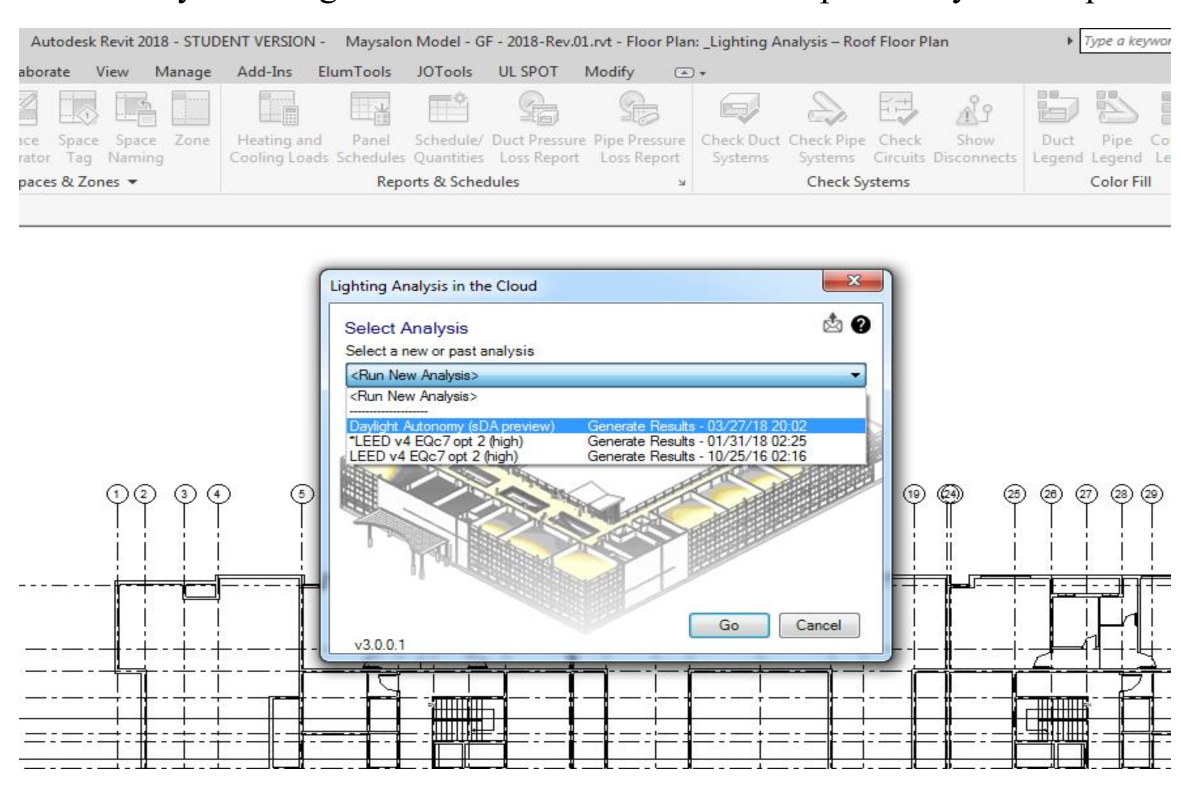


Figure 7-22: Step 10 - generated result appears in lighting analysis dialog box in Autodesk® Revit 2017 and 2018

User will be prompted with a dialog box with a summary of your results. Results summaries will provide guidance on how to improve design to achieve LEED requirements as well as more information about the metrics. Figure 7-23 shows results summary dialog box.

11. You can use the *Section Box* to view the results in 3D or open the corresponding "*_Lighting*" floor plan.

Visual results and schedule results will present sDA300/50 and ASE1000/250 results, sDA and ASE Annual Hours, as well as combined metric results.

12. You can toggle between different analysis visualizations by selecting the analysis plane and changing the **Analysis Configuration** in the **Properties**.

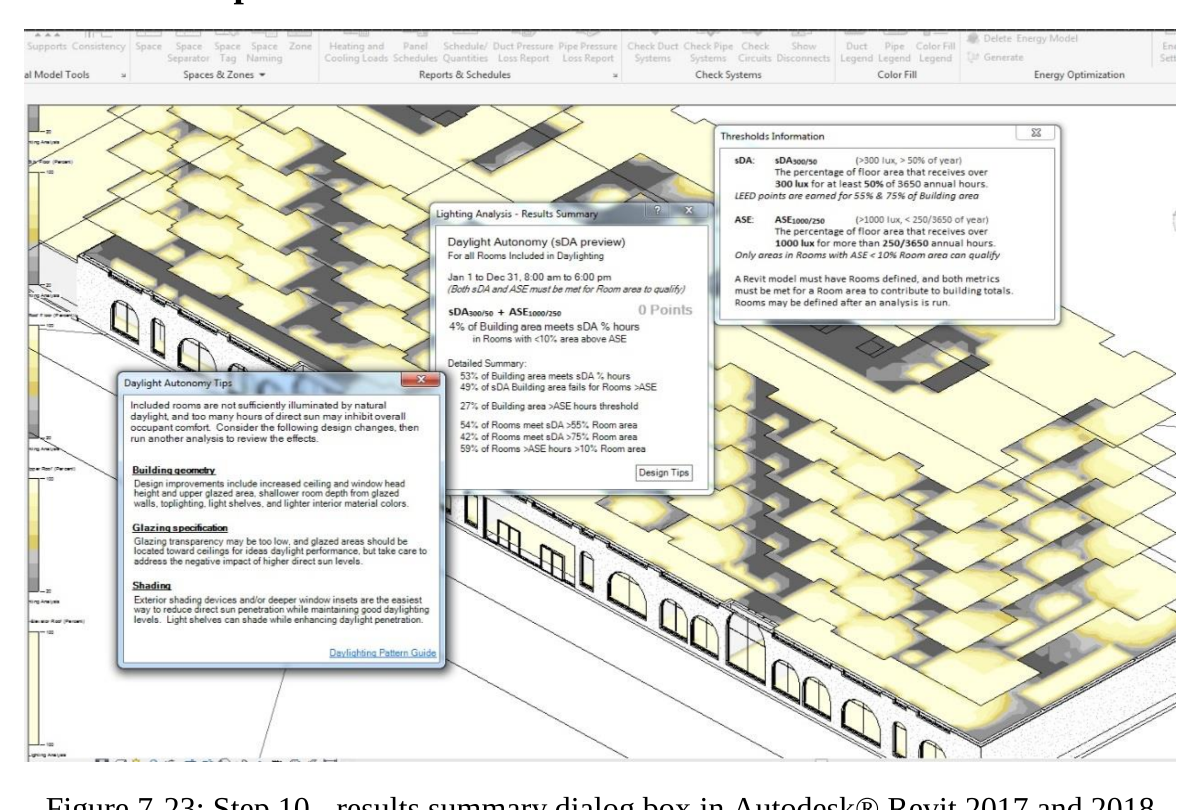


Figure 7-23: Step 10 - results summary dialog box in Autodesk® Revit 2017 and 2018

13. Open **_Lighting Analysis Room Schedule**. To get more detail for the rooms included in the analysis.

Any changes made in the schedule do not require you re-run the analysis. Simply select **Lighting** and access the study results to regenerate results considering the information updated in the schedule.

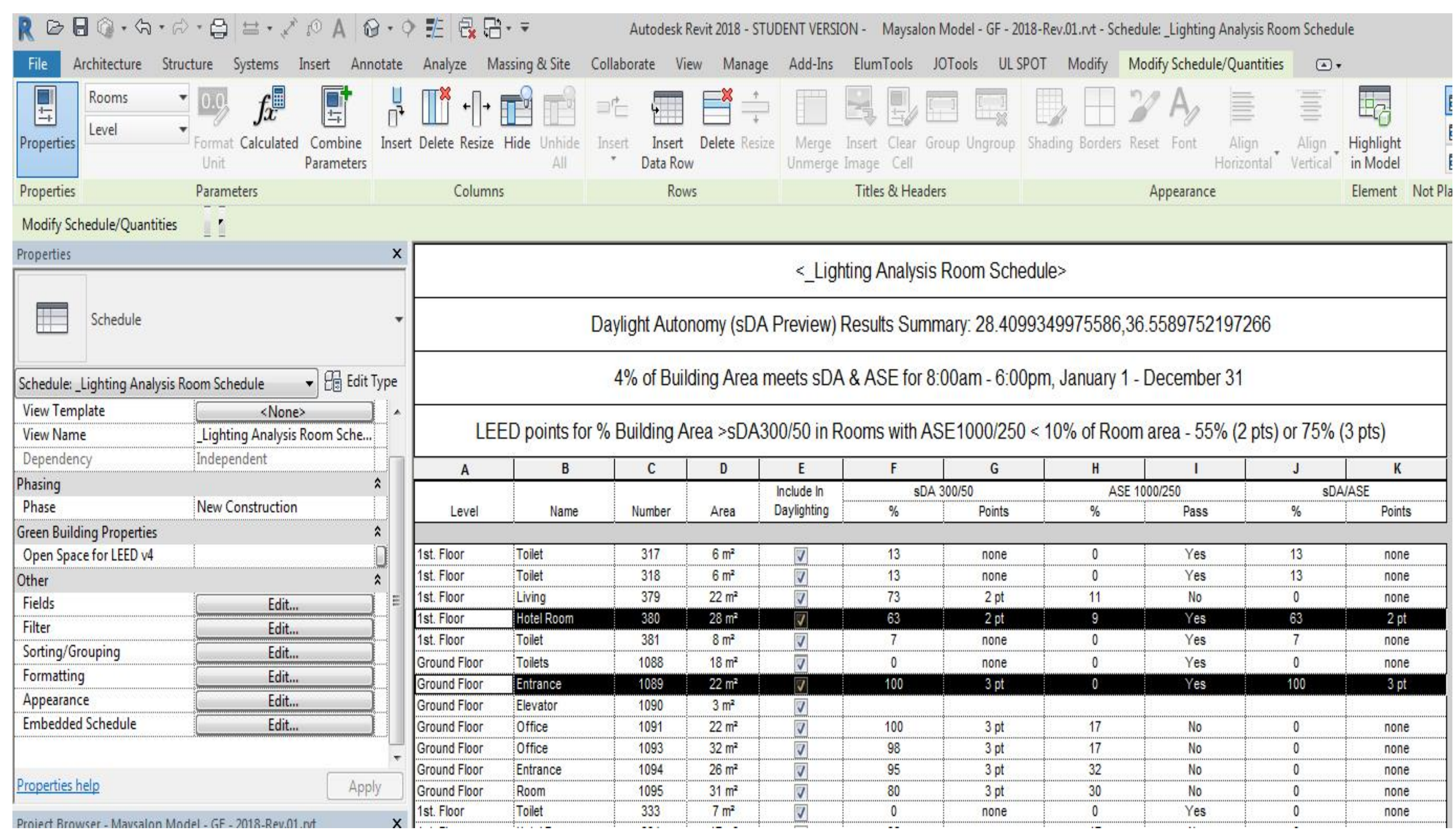


Figure 7-24: Step 13 - Lighting Analysis Room Schedule in Autodesk® Revit 2017 and 2018

Figure 7-24 shows a part of automatically generated Lighting Analysis Room Schedule in Revit 107 and 2018 versions. Any changes made in the schedule do not require user re-run the analysis. Simply select Lighting and access the study results to regenerate results considering the information updated in the schedule.

7.9.1 Daylight Analysis software tools

There are many plugins designed to Daylight calculations listed in Table 7-3.

Table 7-3 : Most popular Daylight analysis tools

Software	Stand Alone	Plugin	Capabilities	Source
LEED sDA & ASE		√	Revit 2017 & 2018	(Autodesk, Light Analysis for Revit 2015)
LA/R		√	Revit 2014: 2016	(Autodesk, LEED sDA & ASE studies. 2016)
DIVA		√	Rhino/Grasshopper	(DIVA 2018)
Sefaira		√	Revit & SketchUp	(Sefaira 2018)
Elum Tools		√	Revit 2017 & 2018	(ElumTools 2018)
Daylight Visualizer 2	√		CAD & SketchUp	(VELUX 2018)
DIALux	√		Any software can export the following file formats: (IFC, STF, DWG, DXF, IES, or LDT)	(DIAL 2018)
DAYSIM	√	√	DIVA Rhino/Grasshopper & SketchUp	(DAYSIM 2018)
AGi32	√		DWG & DXF	(Analysts 2018)
Lumen FX	√		CAD	(LumenFX 2018)
Radiance	√		CAD	(RADSITE 2018)
Vectorworks Spotlight	√		DWG & DXF	(Vectorworks 2018)

7.10 Artificial lighting analysis tools

To date, the industry standard illumination design software programs lack the ability to easily exchange information with models in the BIM environment. The reason for this is two-fold; current illumination software utilizes a

complete environment approach to the calculation of illuminance which is burdened by the large size of the BIM model, and the complexity of exported geometry from BIM is beyond the needs of practical calculation of work plane or surface illuminance. With today's illumination design software not getting the job done, there exists a distinct need to quickly compute basic illuminance (fc or lux) from electric and daylight sources within individual environments in a BIM model, and tabulate the results in a way consistent with the behavior of the BIM software. "ElumTools" is an example of illumination design software, it's considered a fully-integrated lighting calculation tool for Autodesk® Revit®, it's a calculation Add-in used to predict the performance of electric lighting systems and daylight for the variety of environments existing within an Autodesk® Revit® project. With ElumTools, the need to utilize external software to compute illuminance from light sources placed in Revit is no longer necessary. When ElumTools is installed in Revit, it appears with its own tab on the top menu bar. Selecting the ElumTools tab reveals the icons for the various ElumTools commands. Figure 7-25 shows render result of testing artificial lighting using ElumTools add-in.



Figure 7-25: Artificial lighting analysis using specific add-in ElumTools, by (AMA Consult - UK)

7.11 EXNO - Exterior Noise Calculation

EXNO stands for “Exterior Noise”. It is a Revit-API in order to evaluate the quality of sound insulation of windows according to German Standard DIN 4109:2016-07 “Sound Insulation in Buildings”. Based on an architectural Revit model, with definition of room types, exterior walls, the noise level and used ventilator the sound insulation value and sound insulation class of windows can be calculated, in order to inform the architect, about the required quality of windows in terms of noise protection. Results can be exported to Excel and directly visualized in several views. In addition, EXNO also evaluates the Sound Insulation Class according to VDI 2719. The following steps are the overall order to implement a successful EXNO calculation.

1. Use button “Initialize (Data)”, to create necessary schedules, parameters and views.
2. Definition of several parameters: the room types for rooms needed protection; The function of walls, exterior or interior; the noise level or noise level range for exterior walls and roofs; the density and width of the structure layer from exterior walls and roofs.
3. Use button “Import (Ventilator)”, to choose the “Ventilator.rfa” file for ventilator family. Define some ventilator types if necessary.
4. Select several windows and use button “Set (Ventilator)” to allocate ventilator to selected windows.
5. Use button “Check (Data)” to acquire the validation of data for calculation.
6. Use button “All (Calculate)” to run the calculation. If you don’t want to calculate all the rooms, you can select some rooms and use button “Selected (Calculate)”.

7. After the calculation is succeeded, the results can be reviewed in “Room List_EXNO” and some other EXNO-views. An export to Excel file is also supported.

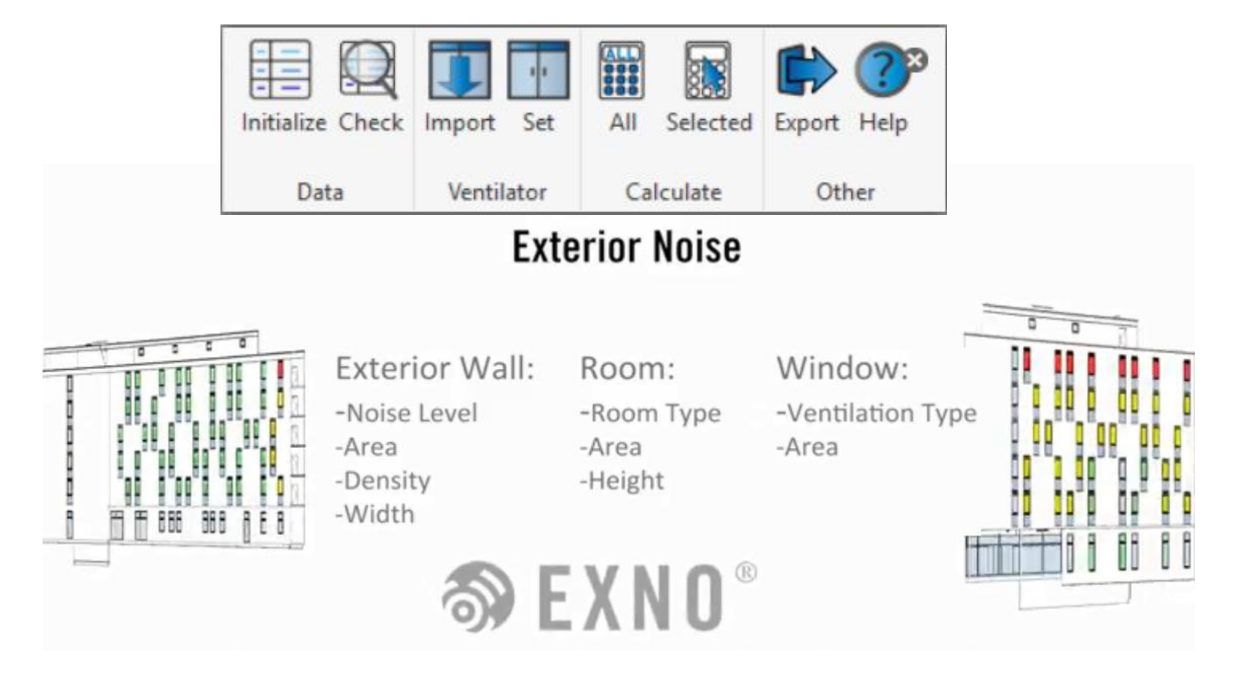


Figure 7-26: EXNO Add-in for Exterior Noise Analysis (werner & Balci)

Table 7-4: Potential Points Assessment on the case study using the proposed methodology of Integration

Credit	Credit Title	Points - New Construction Buildings	Design/ Construction	PROGRAMMING	CONCEPTUAL	SCHEMATIC	DESIGN DEVELOPMENT	CONSTRCUTION DOCUMENTS & After	Required Information Source	Nominated Source	Data Feed Method	Proposed Improvement	Potential points after Proposed Methodology
INTEGRATIVE PROCESS (IP)													
IP c1	Integrative Process	1	D	•	•	•	•	•	BIM Implementation plan	Project Manager	Documentation	Any	1
Possible IP Category Points Per Rating System:		**1**							**Possible SS Category Points Per Rating System:**				**1**
LOCATION and TRANSPORTATION (LT)													
TL c1	LEED for Neighborhood Development Location	16	D	•					Outsource	USGBC	Add-on (Drop List)	API Add-on & Export IFC file for Feedback	16
TL c2	Sensitive Land Protection	1	D	•					Outsource	Local Authority	Add-on (Drop List)		1
TL c3	High Priority Site	2	D	•					Outsource	Local Authority	Add-on (Drop List)		2
TL c4	Surrounding Density and Diverse Uses	5	D	•					Calculations on map	Calculations on map	Add-on (Calculation)		5
TL c5	Access to Quality Transit	5	D	•					Calculations on map	Calculations on map	Add-on (Calculation)		5
TL c6	Bicycle Facilities	1	D	•					Calculations on map	Calculations on map	Add-on (Calculation)		1
TL c7	Reduced Parking Footprint	1	D	•					Manual input	Design Team	Add-on (Drop List)		1
TL c8	Green Vehicles	1	D	•					Manual input	Design Team	Add-on (Drop List)		1
Possible LT Category Points Per Rating System:		**16**							**Possible LT Category Points**				**16**

SUSTAINABLE SITES (SS)														
SS c1	Site Assessment	1	D	•					VAR	Design Team	Add-on (Drop List)	API Add-on & Export IFC file for Feedback	1
SS c2	Site Development—Protect or Restore Habitat	2	D	•					Manual input	Design Team	Manual input		2
SS c3	Open Space	1	D	•	•	•			Model Calculation	Model Calculations	Add-on (Calculation)		1
SS c4	Rainwater Management	3	D	•	•	•			Manual input	Design Calculations	Manual input		3
SS c5	Heat Island Reduction	2	D	•	•	•	•		Manual input	Design Calculations	Manual input		2
SS c6	Light Pollution Reduction	1	D			•	•		Not applicable in design phases				0
Possible SS Category Points Per Rating System:		10							Possible SS Category Points Per Rating System:				9
WATER EFFICIENCY (WE)													
WE c1	Outdoor Water Use Reduction	2	D	•	•	•	•		Manual input	Design Calculations	Manual input		2
WE c2	Indoor Water Use Reduction	6	D	•	•	•	•		Available in GBS Calculation				6
WE c3	Cooling Tower Water Use	2	D			•	•		Available in GBS Calculation				2
WE c4	Water Metering	1	D			•	•		Not applicable in design phases				0
Possible WE Category Points Per Rating System:		11							Possible WE Category Points Per Rating System:				10
ENERGY and ATMOSPHERE (EA)													
EA c1	Enhanced Commissioning	6	C					•	Not Ablicable in design phases				0
EA c2	Optimize Energy Performance	18	D	•	•	•	•		Available in Autodesk Insight and other				18
EA c3	Advanced Energy Metering	1	D			•	•		Not applicable in design phases				0
EA c4	Demand Response	2	C	•				•	Not applicable in design phases				0
EA c5	Renewable Energy Production	3	D	•	•	•	•		Not applicable in design phases				0
EA c6	Enhanced Refrigerant Management	1	D		•	•	•		manual input	Design Calculations	Manual input		1
EA c7	Green Power and Carbon Offsets	2	C	•				•	Not applicable in design phases				0
Possible EA Category Points Per Rating System:		33							Possible SS Category Points Per Rating System:				19

MATERIALS and RESOURCES (MR)										
MR c1	Building Life Cycle Impact Reduction	5	C			•	•		Available in "One Click LCA" Add-in and other	5
MR c2	Building Product Disclosure and Optimization---Environmental Product Declarations	2	C			•	•		**Not applicable in design phases**	0
MR c3	Building Product Disclosure and Optimization---Sourcing of Raw Materials	2	C			•	•		**Not applicable in design phases**	0
MR c4	Building Product Disclosure and Optimization---Material Ingredients	2	C			•	•		**Not applicable in design phases**	0
MR c5	Construction and Demolition Waste Management	2	C					•	**Not applicable in design phases**	0
Possible MR Category Points Per Rating System:		**13**							**Possible MR Category Points Per Rating System:**	**5**
INDOOR ENVIRONMENTAL QUALITY (EQ)										
EQ c1	Enhanced Indoor Air Quality Strategies	2	D	•	•	•	•		Available in Autodesk Revit	2
EQ c2	Low-Emitting Materials	3	C			•	•		Material Properties Design Team Autodesk Revit	3
EQ c3	Construction Indoor Air Quality Management Plan	1	C	•	•			•	**Not applicable in design phases**	0
EQ c4	Indoor Air Quality Assessment	2	C					•	**Not applicable in design phases**	0
EQ c5	Thermal Comfort	1	D			•	•		Available in Autodesk Revit & Design Builder	1
EQ c6	Interior Lighting	2	D			•	•		Partially Available in Autodesk Revit Elum Tools & DIAlux evo	1
EQ c7	Daylight	3	D	•	•	•	•		Available in Autodesk Revit and Insight & IESVE	3
EQ c8	Quality Views	1	D	•	•	•	•		Available in Autodesk Revit other	1
EQ c9	Acoustic Performance	1	D			•	•		Available in Autodesk Revit and EXNO Add-in	1
Possible EQ Category Points Per Rating System:		**16**							**Possible EQ Category Points Per Rating System (Using BIM):**	**12**
Total LEED v4 Points for New Construction (NC)		**100**							**Potential Points project may achieve using BIM programs**	**72**

Table 7-5: Extracted information of the Location and Transportation Credit category

LOCATION and TRANSPORTATION (LT)				Verify Project Data				
Credit Code	**Credit Title**	**Option**	**Options**	**Data Inputs**	**Points**	**Maximum Points**	**Proposed Software**	**Notes**
LTc1	LEED for Neighborhood Development Location		The project location is within the boundary of a development certified under LEED for Neighborhood Development (Stage 2 or Stage 3 under the Pilot or 2009 rating systems, Certified Plan or Certified Project under the LEED v4 rating system).	Gold	**0** **0** **12** **0**	12	**AutoCAD map 3d ArcGIS Google Maps**	**If project meet these option, cannot get more points under LT credit category**
LT c2	Sensitive Land Protection?	a	Locate the development footprint on land that has been previously developed	YES	**1**	1		**Data must be loaded on ArcGIS file provided from local authority**
		b	**(OR)** Locate the development footprint on land that has been previously developed that meet LEED v4 requirement	YES	**1**			
LT c3	High Priority Site	a	Locate the project on an infill location in a historic district.	YES	**1**	**2**		**Data must be loaded on ArcGIS file provided from local authority**
		b	**(OR)** Locate the project on a location meets LEED v4 requirement	YES	**1**			
		c	**(OR)** Locate on a brownfield where soil or groundwater contamination has been identified, and where the local, state, or national authority (whichever has jurisdiction) requires its remediation. Perform remediation to the satisfaction of that authority.	YES	**2**			
LT c4	Surrounding Density and Diverse Uses		**Locate on a site whose surrounding existing density within a ¼-mile [400-meter] radius of the project boundary meets the values in Table 1. Use either the "separate residential and nonresidential densities" or the "combined density" values.**			**5**	**AutoCAD map 3d ArcGIS Google Maps**	**API-EVAL add-on can calculate density & diverse uses**
		a	Combined density = - (5,050 Square meters per hectare of buildable land) - Residential density (17.5 DU/hectare) - Nonresidential density (0.5 FAR)	YES	**2**			
		b	Combined density = - (8,035 Square meters per hectare of buildable land)	YES	**3**			

			- Residential density (30 DU/hectare) - Nonresidential density (0.8 FAR)					
		d	Diverse uses - within ½-mile (800-meter) walking distance of the main entrance of four to seven	YES	**1**			
		e	Diverse uses - within ½-mile (800-meter) walking distance of the main entrance of ≥ eight to seven	YES	**2**			
LT c5	Access to Quality Transit		**Locate any functional entry of the project within a ¼-mile (400 meter) walking distance of existing or planned bus, streetcar, or informal transit stops:**			**5**	**AutoCAD map 3d ArcGIS Google Maps**	**Need an add-on can calculate Transit options according to specific equation**
		a	Weekday trips (72) & Weekend trips (40)	YES	**1**			
		b	Weekday trips (144) & Weekend trips (108)	YES	**3**			
		c	Weekday trips (360) & Weekend trips (216)	YES	**5**			
			Locate any functional entry of the project within a ½-mile (800-meter) walking distance of existing or planned bus rapid transit stops, light or heavy rail stations, commuter rail stations or ferry terminals:					
		d	Weekday trips (24) & Weekend trips (6)	YES	**1**			
		e	Weekday trips (40) & Weekend trips (8)	YES	**2**			
		f	Weekday trips (60) & Weekend trips (12)	YES	**3**			
LT c6	Bicycle Facilities	a	**Bicycle network**			**1**		**API-EVAL add-on can calculate density & diverse uses**
			Design or locate the project such that a functional entry and/or bicycle storage is within a 200-yard (180-meter) walking distance or bicycling distance from a bicycle network that connects to at least one of the following: - at least 10 diverse uses; - a school or employment center, if the project total floor area is 50% or more residential; or - a bus rapid transit stop, light or heavy rail station, commuter rail station, or ferry terminal. **All destinations must be within a 3-mile (4800-meter) bicycling distance of the project boundary.**	YES	**0.5**			
		b	**(AND) Bicycle Storage and Shower Rooms**					

		b-1	**Case 1. Commercial or institutional projects:** - Provide short-term bicycle storage ≥ 2.5% of all peak visitors, but ≥ storage spaces per building. - Provide long-term bicycle storage ≥ 5% of all regular building occupants, but ≥ storage spaces per building in addition to the short-term bicycle storage space. - Provide at least one on-site shower with changing facility for the first 100 regular building occupants and one additional shower for every 150 regular building occupants thereafter.	YES	**0.25**			
		b-2	**Case 2. Residential projects:** - Provide short-term bicycle storage ≥ 2.5% of all peak visitors, but ≥ storage spaces per building. - Provide long-term bicycle storage ≥ 30% of all regular building occupants, but ≥ storage spaces per building in addition to the short-term bicycle storage space.	YES	**0.25**			
		b-3	**Case 3. Mixed-use projects:** Meet the Case 1 and Case 2 storage requirements for the nonresidential and residential portions of the project, respectively.					
LT c7	Reduced Parking Footprint	a	**Do not exceed the minimum local code requirements for parking capacity.** **Provide parking capacity that is a percentage reduction below the base ratios recommended by the Parking Consultants Council, as shown in the Institute of Transportation Engineers' Transportation Planning Handbook, 3rd edition, Tables 18-2 through 18-4.**			**2**	**REVIT**	**Need information bar to be available in REVIT**
			Case 1.a Baseline location Projects that have not earned points under LT Credit Surrounding Density and Diverse Uses or LT Credit Access to Quality Transit must achieve a 20% reduction from the base ratios.	YES	**1**			
			Case 1.b Baseline location Projects that have not earned points under LT Credit Surrounding Density and Diverse Uses or LT Credit Access to Quality Transit must achieve a 40% reduction from the base ratios.	YES	**2**			

			Case 2. Dense and/or transit-served location Projects earning 1 or more points under either LT Credit Surrounding Density and Diverse Uses or LT Credit Access to Quality Transit must achieve a 40% reduction from the base ratios.	YES	**1**			
			Case 2. Dense and/or transit-served location Projects earning 1 or more points under either LT Credit Surrounding Density and Diverse Uses or LT Credit Access to Quality Transit must achieve a 60% reduction from the base ratios.	YES	**2**			
LT c8	Green Vehicles		**Designate 5% of all parking spaces used by the project as preferred parking for green vehicles. Clearly identify and enforce for sole use by green vehicles. Distribute preferred parking spaces proportionally among various parking sections (e.g. between short-term and long-term spaces).** **Green vehicles must achieve a minimum green score of 45 on the American Council for an Energy Efficient Economy (ACEEE) annual vehicle rating guide (or local equivalent for projects outside the U.S.)**			**1**	**REVIT**	**Add New Parameter And New Family**
		a	**Option 1. Electric vehicle charging:** Install electrical vehicle supply equipment (EVSE) in 2% of all parking spaces used by the project.	YES	**1**			
		b	**(OR) Option 2. Liquid, gas, or battery facilities:** Install liquid or gas alternative fuel fueling facilities or a battery switching station capable of refueling a number of vehicles per day equal to at least 2% of all parking spaces.	YES	**1**			
Possible LT Category Points						**16**		

YES	Drop list (YES/NO) - User Input

Table 7-6: Extracted information of the Sustainable Sites Credit category

SUSTAINABLE SITES (SS)				Verify Project Data				
Credit Code	Credit Title	Option #	Options	Data Inputs	Points	Maximum Points	Data loaded on Software	Notes
SSc1	Site Assessment		To assess site conditions before design to evaluate sustainable options and inform related decisions about site design. Complete and document a site survey or assessment1 that includes the following information: (Topography-Hydrology-Climate-Vegetation-Soils-Human use-Human health effects) The survey or assessment should demonstrate the relationships between the site features and topics listed above and how these features influenced the project design; give the reasons for not addressing any of those topics.	YES	**1**	**1**		
SS c2	Site Development—Protect or Restore Habitat	a	**on-site restoration:** Using native or adapted vegetation, restore 30% (including the building footprint) of all portions of the site identified as previously disturbed. Projects that achieve a density of 1.5 floor-area ratio may include vegetated roof surfaces in this calculation if the plants are native or adapted, provide habitat, and promote biodiversity.	YES	**2**	**2**		
		b	**(OR) financial support:** Provide financial support equivalent to at least $0.40 per square foot (US$4 per square meter) for the total site area (including the building footprint)	YES	**1**			
SS c3	Open Space		Provide outdoor space greater than or equal to 30% of the total site area (including building footprint). A minimum of 25% of that outdoor space must be vegetated (turf grass does not count as vegetation) or have overhead vegetated canopy.	YES	**1**	**1**		

SS c4	Rainwater Management	a	**Percentile of rainfall events:**					3		
		a-1	**95th percentile:** manage on site the runoff from the developed site for the 95th percentile of regional or local rainfall events using low-impact development (LID) and green infrastructure. Use daily rainfall data and the methodology in the U.S. Environmental Protection Agency (EPA) Technical Guidance on Implementing the Storm Water Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act to determine the 95th percentile amount.			YES	**2**			
		a-2	**(OR) 98th percentile:** Achieve Path 1 but for the 98th percentile of regional or local rainfall events, using LID and green infrastructure.			YES	**3**			
		a-3	**(OR) Zero lot line projects only – 85th Percentile:** The following requirement applies to zero lot line projects in urban areas with a minimum density of 1.5 FAR. In a manner best replicating natural site hydrology processes, manage on site the runoff from the developed site for the 85th percentile of regional or local rainfall events, using LID and green infrastructure.			YES	**3**			
		b	**(OR) Natural land cover conditions:** Manage on site the annual increase in runoff volume from the natural land cover condition to the post developed condition.			YES	**3**			
SSc5	Heat Island Reduction	a	**Nonroof and roof** **Meet the following criterion:** (Area of Nonroof Measures/.5 + Area of Nonroof Measures/.75 + Area of Vegetated Roof/.75) >= Total Site Paving Area + Total Roof Area	**Area of Nonroof Measures =**	**20**	**TRUE**	**2**	**2**		
				Area of Nonroof Measures =	20					
				Area of Vegetated Roof =	10					
				Total Site Paving Area =	**20**					
				Total Roof Area =	20					

			High-reflectance roof: Use roofing materials that have an SRI equal to or greater than the values shown below. Meet the three-year aged SRI value. If three-year aged value information is not available, use materials that meet the initial SRI value.							
			Low-sloped roof =< 2:12	**Initial SRI**	**3-year aged SRI**	**TRUE**				
				83	65					
			Steep-sloped roof > 2:12	**Initial SRI**	**3-year aged SRI**					
				39	32					
			Vegetated roof: Install a vegetated roof.	**YES**		**TRUE**				
		b	**(OR)** **Parking under cover:**							
		b1	Total parking spaces=	100		**TRUE**	**2**			
			Parking spaces under cover=	75						
			3-year aged SRI	32						
			Initial SRI	39						
		b2	Parking vegetated roof	**YES**						
		b3	covered by energy generation systems, such as solar thermal collectors, photovoltaics, and wind turbines	**YES**						
	Light Pollution Reduction		**Not Applicable in BIM software**			**Not Applicable in BIM software**				
Possible SS Category Points								**9**		

000	User Input

Table 7-7: Extracted information of the Water Efficiency Credit category

WATER EFFICIENCY (WE)						Verify Project Data				
Credit Code	**Credit Title**	**Option**	**Options**			**Data Inputs**	**Points**	**Maximum Points**	**Data loaded on Software**	**Notes**
WE c1	Outdoor Water Use Reduction	a	**No irrigation required:** Landscape does not require a permanent irrigation system beyond a maximum two-year establishment period.			YES	**2**	**2**	**Revit**	**Data must be loaded on Revit & green Building Studio by design team**
		b	**Reduced irrigation:** Reduce the project's landscape water requirement (LWR) by	**Baseline**	**Actual**					
		b-1	at least 50% from the calculated baseline for the site's peak watering month	**100**	**50**	YES	**1**			
		b-2	100% from the calculated baseline for the site's peak watering month		**100**	YES	**2**			
WE c2	Indoor Water Use Reduction		**Indoor Water Use Reduction:**	**Baseline**	**Percentage reduction**			**8**	**Revit & green Building Studio**	**Data must be loaded on Revit & green Building Studio by design team**
			Further reduce fixture and fitting water use from the calculated baseline in WE Prerequisite Indoor Water Use Reduction. Additional potable water savings can be earned above the prerequisite level using alternative water sources. Include fixtures and fittings necessary to meet the needs of the occupants. Some of these fittings and fixtures may be outside the tenant space (for Commercial Interiors) or project boundary	100	25	YES	**1**			
					30	YES	**2**			
					35	YES	**3**			
					40	YES	**4**			
					45	YES	**5**			
					50	YES	**6**			
WE c3	Cooling Tower Water Use					YES	**2**		**Green Building Studio**	
WE c4	Water Metering		**Not Applicable in design phases**			**Not Applicable in design phases**				
Possible WE Category Points								**10**		

000	User Input

Table 7-8: Extracted information of the ENERGY and ATMOSPHERE Credit category

ENERGY and ATMOSPHERE (EA)						Verify Project Data				
Credit Code	**Credit Title**	**Option**	**Options**			**Data Inputs**	**Points**	**Maximum Points**	**Data loaded on Software**	**Notes**
EA c1	Enhanced Commissioning		**Not Applicable in design phases**							
EA c2	Optimize Energy Performance		Minimum Energy Performance, percentage improvement in the proposed building performance rating compared with the baseline	Baseline	Percentage improvement			**18**		
				100	**50**	NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						YES	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**0**			
						NO	**18**			
EA c3	Advanced Energy Metering		**Not Applicable in design phases**							

EA c4	Demand Response		**Not Applicable in design phases**							
EA c5	Renewable Energy Production		**Not Applicable in design phases**							
EA c6	Enhanced Refrigerant Management	a	**No refrigerants or low-impact refrigerants:** Do not use refrigerants, or use only refrigerants (naturally occurring or synthetic) that have an ozone depletion potential (ODP) of zero and a global warming potential (GWP) of less than 50	**ODP**	**GWP**	**TRUE**	**1**	**0**		
		b	**Calculation of refrigerant impact:** Select refrigerants that are used in heating, ventilating, air-conditioning, and refrigeration (HVAC&R) equipment to minimize or eliminate the emission of compounds that contribute to ozone depletion and climate change. The combination of all new and existing base building and tenant HVAC&R equipment that serve the project must comply with the following formula:							
			LCODP: Lifecycle Ozone Depletion Potential (kg CFC 11/(kW/year)) =	**1.95E-05**	**196.95**	**FALSE**	**0**			
			LCGWP: Lifecycle Direct Global Warming Potential (kg CO2/kW-year) =	**0.00195**						
			GWPr: Global Warming Potential of Refrigerant (0 to 12,000 kg CO2/kg r) =	**1**						
			ODPr: Ozone Depletion Potential of Refrigerant (0 to 0.2 kg CFC 11/kg r) =	**0.01**						
			Lr: Refrigerant Leakage Rate (2.0%) =	**2%**						
			Mr: End-of-life Refrigerant Loss (10%) =	**10%**						
			Rc: Refrigerant Charge (0.065 to 0.65 kg of refrigerant per kW of AHRI rated or Eurovent Certified cooling capacity) =	**0.065**						
			Life: Equipment Life (10 years; default based on equipment type, unless otherwise demonstrated) =	**10**						
EA c7	Green Power and Carbon Offsets	b	**Not Ablicable in design phases**							
Possible EA Category Points								**19**		

000	User Input

Table 7-9: Extracted information of the MATERIALS and RESOURCES Credit category

MATERIALS and RESOURCES (MR)						Verify Project Data				
Credit Code	**Credit Title**	**Option**	**Options**			**Data Inputs**	**Points**	**Maximum Points**	**Data loaded on Software**	**Notes**
MR c1	Building Life Cycle Impact Reduction	a	**historic building reuse:** Maintain the existing building structure, envelope, and interior nonstructural elements of a historic building or contributing building in a historic district			YES	5	5	**Revit**	**Data must be loaded on Revit by design team**
		b	**Renovation of abandoned or blighted building:** Maintain at least 50%, by surface area, of the existing building structure, enclosure, and interior structural elements for buildings that meet local criteria of abandoned or are considered blight.			YES	5			
		c	**whole-building life-cycle assessment :** conduct a life-cycle assessment of the project's structure and enclosure that demonstrates a minimum of **10%** reduction, compared with a baseline building in at least three of the six impact categories listed below	**baseline Building**	**Actual Reduction**					
			global warming potential (greenhouse gases), in kg CO2e	**100**	**5**	FALSE	**3**			
			depletion of the stratospheric ozone layer, in kg CFC-11	**100**	**11**	TRUE				
			acidification of land and water sources, in moles H+ or kg SO2	**100**	**12**	TRUE				
			eutrophication, in kg nitrogen or kg phosphate	**100**	**10**	TRUE				
			formation of tropospheric ozone, in kg NOx, kg O3 eq, or kg ethene	**100**	**6**	FALSE				

			depletion of nonrenewable energy resources, in MJ	**100**	**2**	FALSE				
		d	**building and material reuse:** Reuse or salvage building materials from off site or on site as a percentage of the surface area			**Not Applicable in design phases**				
MR c2	Building Product Disclosure and Optimization--- Environmental Product Declarations		**Not Applicable in design phases**			**Not Applicable in design phases**				
MRc3	Building Product Disclosure and Optimization--- Sourcing of Raw Materials		**Not Applicable in design phases**			**Not Applicable in design phases**				
MR c4	Building Product Disclosure and Optimization--- Material Ingredients		**Not Applicable in design phases**			**Not Applicable in design phases**				
MR c5	Construction and Demolition Waste Management		**Not Applicable in design phases**			**Not Applicable in design phases**				
Possible MR Category Points								**5**		

000	User Input

Table 7-10: Extracted information of the INDOOR ENVIRONMENTAL QUALITY Credit category

INDOOR ENVIRONMENTAL QUALITY (EQ)						Verify Project Data				
Credit Code	Credit Title	Option	Options			Data Inputs	Points	Maximum Points	Data loaded on Software	Notes
EQ c1	Enhanced Indoor Air Quality Strategies	a	**Enhanced IAQ strategies:**					2		
		a-1	**Mechanically ventilated spaces:**							
		-	Entryway systems		YES	TRUE	1			
		-	Interior cross-contamination prevention		YES					
		-	Filtration		YES					
		a-2	**Naturally ventilated spaces:**							
		-	entryway systems; and		YES					
		-	natural ventilation design calculations		YES					
		a-3	**Mixed-mode systems:**							
		-	Entryway systems		YES					
		-	Interior cross-contamination prevention		YES					
		-	Filtration		YES					
		-	natural ventilation design calculations		YES					
		-	mixed-mode design calculations		YES					
		b	**Additional enhanced IAQ strategies:**							
		b-1	**Mechanically ventilated spaces (select one):**							
		-	exterior contamination prevention	YES	TRUE	TRUE	1			
		-	increased ventilation	NO						
		-	carbon dioxide monitoring	NO						
		-	additional source control and monitoring	NO						
		b-2	**Naturally ventilated spaces (select one):**							
		-	exterior contamination prevention	YES	TRUE					
		-	additional source control and monitoring	NO						
		-	natural ventilation room by room calculations	NO						

		b-3	**Mixed-mode systems (select one):**							
		-	exterior contamination prevention	NO	TRUE					
		-	increased ventilation	NO						
		-	additional source control and monitoring	NO						
		-	natural ventilation room-by-room calculations	YES						
EQ c2	Low-Emitting Materials		This credit includes requirements for product manufacturing as well as project teams. It covers volatile organic compound (VOC) emissions in the indoor air and the VOC content of materials, as well as the testing methods by which indoor VOC emissions are determined. Different materials must meet different requirements to be considered compliant for this credit. The building interior and exterior are organized in seven categories, each with different thresholds of compliance. The building interior is defined as everything within the waterproofing membrane. The building exterior is defined as everything outside and inclusive of the primary and secondary weatherproofing system, such as waterproofing membranes and air- and water-resistive barrier materials.					**3**		
		a	**Product Category Calculations:**	Threshold	Actual					
		a-1	Interior paints and coatings applied on site, 90% by volume, VOC emmesions	**100%**	**100%**	YES				
		a-2	Interior adhesives and sealants applied on site (including flooring adhesive), 90% by volume, VOC emmesions	**100%**	**100%**	YES				
		a-3	Flooring	**100%**	**100%**	YES				
		a-4	Composite wood	**100%**	**100%**	YES				
		a-5	Ceilings, walls, thermal, and acoustic insulation	**100%**	**100%**	YES				
		a-6	Furniture (include in calculations if part of scope of work), (by cost)	**90%**	**90%**	YES				
		a-7	Healthcare and Schools Projects only: Exterior applied products	**Not Ablicable in LEED New Construction**						
		b	**Budget Calculation Method** If some products in a category do not meet the criteria, project teams may use the budget calculation method	**Budget**	**Percentage of total**					
		b-1	≥ 50% and < 70%	**100**	**60**	YES	**1**			

			≥ 70% and < 90%	**100**	**80**	YES	**2**			
			≥ 90%	**100**	**95**	YES	**3**			
EQ c3	Construction Indoor Air Quality Management Plan		**Not Applicable in design phases**							
EQc4	Indoor Air Quality Assessment		**Not applicable in design phases**							
EQ c5	Thermal Comfort	a	**Thermal comfort design:**							
		a-1	**ASHRAE Standard 55-2010:**Design heating, ventilating, and air-conditioning (HVAC) systems and the building envelope to meet the requirements of ASHRAE Standard 55–2010, Thermal Comfort Conditions for Human Occupancy, with errata or a local equivalent.For natatoriums, demonstrate compliance with ASHRAE HVAC Applications Handbook, 2011 edition, Chapter 5, Places of Assembly, Typical Natatorium Design Conditions, with errata.		YES	TRUE	**1**	1	Revit	
		a-2	**ISO and CEN Standards:** Design HVAC systems and the building envelope to meet the requirements of the applicable standard: ISO 7730:2005, Ergonomics of the Thermal Environment, analytical determination and interpretation of thermal comfort, using calculation of the PMV and PPD indices and local thermal comfort criteria; and CEN Standard EN 15251:2007, Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings, addressing indoor air quality, thermal environment, lighting, and acoustics, Section A2.		NO	FALSE	**0**		Revit	

		b	**Thermal comfort control:** Provide individual thermal comfort controls for at least 50% of individual occupant spaces. Provide group thermal comfort controls for all shared multi-occupant spaces, and for any individual occupant spaces without individual controls. Thermal comfort controls allow occupants, whether in individual spaces or shared multi-occupant spaces, to adjust at least one of the following in their local environment: air temperature, radiant temperature, air speed, and humidity.	NO	FALSE	**0**		Revit	
EQ c6	Interior Lighting	a	**Lighting control:** For at least 90% of individual occupant spaces, provide individual lighting controls that enable occupants to adjust the lighting to suit their individual tasks and preferences, with at least three lighting levels or scenes (on, off, midlevel). Midlevel is 30% to 70% of the maximum illumination level (not including daylight contributions).	**YES**	TRUE	**1**	**1**	**Revit**	
		b	**Not Ablicable in BIM software**						
EQ c7	Daylight	b	**Calculated by Autodesk insight lighting analysis**	**YES**	TRUE	**3**	**5**	**Revit/Insight**	
EQ c8	Quality Views		**Can be visualized in render process by any modeling software**	**YES**	TRUE	**1**			
EA c9	Acoustic Performance	b	**Calculated by EXNO Plugin for acoustics**	**YES**	TRUE	**1**		**Revit/EXNO**	
Possible LT Category Points							**12**		

YES	User Input

CHAPTER 8

Summary and Concluding Remarks

8.1 Summary and research contribution

The current research divided into two parallel paths; the first is a literature review of the relevant researches in the past 7 years. The second is a questionnaire distributed to specialists in both sustainable design and BIM fields. In order to investigate the ability of BIM-Based sustainable tools to simulate a particular green building rating system using a simple approach based on suggested framework module. In addition, the research proposed a programmed Excel Sheet to produce a green building assessment template according to LEED® v4 rating system rating system. The proposed framework applied on a hotel project as a verification case study pursue to achieve green building certification using LEED® v4 rating system for new construction (NC) projects. The research findings concluded as follows:

1. Improve the database management system (DBMS) between local authorities/outsources and design firms in field of GIS-BIM database became a mandatory for more accurate simulation results and significant saving of time and cost.
2. BIM-based sustainable design process needs to be managed and developed properly. Therefore, understanding the level of development (LOD) is essential for successful integration.
3. BIM-based sustainable simulation results will be improved when all design/performance analysis team members work collaboratively within an iterative process of design decision-making.
4. BIM-based software can be used in simple interoperability framework to easiness the green building certification process.

5. BIM-based software can support the design team to achieve (72) points in LEED v4 NC certification process.
6. BIM-based software can utilize a simplified approach as a pre-assessment process for LEED v4 NC projects. As well, a similar study can be applied for other sustainable building rating system.
7. The main contribution of this research is a more effective consideration of the power of information sharing within integration process between design team and governmental departments as well as a better integration of benchmarking tools into the process. Attribute data within the BIM model can drive better facilities management and LCA together with refurbishments through the expected life of the facility

8.2 Research Contribution

The contributions of this research reside in the following:

1. Developing a simple approach to enhance sustainable design by integrating the functionalities of BIM tools. The integration is demonstrated by looking at the latest version of both, the most popular green building rating system (LEED® v4) and the most common and prevailing BIM software (Autodesk® Revit 2017 & 2018).
2. Developing an integrated model that incorporates an information tradeoff steps, which engage design team with the other decision makers and governmental municipalities. This engagement provides beneficial gains for all parties, on the first hand, design team can get a ready modeled file contains GIS data base from the municipality. On the other hand, the municipality will get the model back contains the new project data which in turn will add to the city data base. This

integration process leads to easy upgrade from BIM (Building Information Modeling) to CIM (City Information Modeling).

3. The developed model will help the design team in analyzing how different alternatives meet LEED® v4 (NC) credits. Furthermore, the proposed model provides a general idea of the LEED® v4 (NC) credit categories and related strategies.

8.3 Limitations of the Developed approach

It must be emphasized that the developed approach and produced Excel sheet can only be used to prepare sustainable design using LEED® v4 (NC) rating system, and accordingly generates sustainability related information for building projects that are determined by USGBC as a new construction projects. The design team may use the proposed integration process and Excel sheet to pursue pre-assessment tool according to LEED® v4 certification process. In addition, this research included LEED® v4 (NC) credit categories without addressing any analysis related to the prerequisites.

Listed below are the proposed approach specific limitations:

- The simulated model applied in an existing project and the results should be validated. This considered the next step needed to make the results of this research truly helpful to professionals in the construction industry.
- The modeled materials for building envelope assumed to meet the low energy consumption strategies and LEED® v4 requirement and in order to verify the maximum potential LEED® v4 points. That mean the specified materials used in the model are not necessarily consistent with the material actually used in the real building.
- The used 3D modeling software is not the only program could use in the proposed process, design team can use a lot of 3D program (i.e.

Sketch up, FormIt, ArchiCAD,..atc.), In addition the preliminary weather studies could be done by other programs (i.e. Rhinoceros& Grass Hoper with related Add-ins, Sefaira,…atc).

- This study focused only at the integration between BIM and sustainability through the application of only LEED® v4 (NC) credits. The results thus were limited to LEED® instead of the general framework of sustainability. Moreover, the Add-in application developed in this research were quite generic. More intensive coding will be desirable to turn the results of this study into actual products.
- The openness of the software's APIs needs to be addressed. Due to the unique circumstances of a project, software users want flexibility to customize the application to serve better their needs in manipulating the model information.

8.4 Recommendations for Future Research

This research can be expanded as follows:

- The future expansion of this research can focus on using BIM's simulation and analysis tools to support the decision-making process for sustainable building assessment at the conceptual stages, through whole Building energy simulation during the project life cycle.
- Reducing the lack of interoperability between the various disciplines involved in design process by developing a semantic responsibility matrix and assign an iterative interoperability between chosen BIM software to match design goals and owner requirement.
- Improve a comprehensive investigation of the accuracy of energy simulation results using BIM tools and provide an easy-to-use way for project stakeholders to predict the potential gains in terms of energy consumption and environmental

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Appendix A. . Questionnaire Analysis

A.1 Questionnaire Frequency

Table A-1: Frequency Table

Location					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Africa	21	16.9	16.9	16.9
	Americas	4	3.2	3.2	20.2
	Asia-Pacific	15	12.1	12.1	32.3
	Europe	5	4.0	4.0	36.3
	MENA (Middle East and North Africa)	79	63.7	63.7	100.0
	Total	124	100.0	100.0	

Company					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Diyar	8	6.5	6.5	6.5
	Civil 99	1	.8	.8	7.3
	Sasaki, Inc.	1	.8	.8	8.1
	Fiorito Egypt	1	.8	.8	8.9
	sustainable solutions	2	1.6	1.6	10.5
	Hilti	1	.8	.8	11.3
	UK Engineering Consultant	1	.8	.8	12.1
	Projacs International	1	.8	.8	12.9
	Midrar development management	1	.8	.8	13.7
	PEC	2	1.6	1.6	15.3
	Sceco	1	.8	.8	16.1
	Envirospace	1	.8	.8	16.9
	Queen's University Belfast	1	.8	.8	17.7
	Bsc	1	.8	.8	18.5
	Saudi Bin Ladin Group	14	11.3	11.3	29.8
	N.A	3	2.4	2.4	32.3
	Eco-Arch. Consultant	1	.8	.8	33.1
	Engineering train est	1	.8	.8	33.9
	kayan architects	1	.8	.8	34.7
	Al Dau Development Real State	1	.8	.8	35.5
	Consolidated Contractors Company	3	2.4	2.4	37.9
	USS Cal Builder	1	.8	.8	38.7
	Dar Al-handasah	11	8.9	8.9	47.6

	Udaar	1	.8	.8	48.4
	Mansoura University	1	.8	.8	49.2
	Siemens	1	.8	.8	50.0
	Kirkuk	1	.8	.8	50.8
	CTU in Prague	2	1.6	1.6	52.4
	Parsons	1	.8	.8	53.2
	AE7	1	.8	.8	54.0
	Confidential	1	.8	.8	54.8
	FACULTY OF ENGINEERING	1	.8	.8	55.6
	Heritage NGO	1	.8	.8	56.5
	el masherek	1	.8	.8	57.3
	ElKhereiji Co.	1	.8	.8	58.1
	Pace Office	1	.8	.8	58.9
	Kaust	1	.8	.8	59.7
	Ehaf	1	.8	.8	60.5
	BEC	1	.8	.8	61.3
	Alghota contradicting company	1	.8	.8	62.1
	Qrma	1	.8	.8	62.9
	Upturn	1	.8	.8	63.7
	Tacoma	1	.8	.8	64.5
	James cubitte	1	.8	.8	65.3
	اكاسيب للمقاولات	1	.8	.8	66.1
	Regen	1	.8	.8	66.9
	Ain Shams University	1	.8	.8	67.7
	Ewan North Contracting Company	1	.8	.8	68.5
	ARB	1	.8	.8	69.4
	Rajhi real estate & development co	1	.8	.8	70.2
	Redco almana	1	.8	.8	71.0
	HUTA	1	.8	.8	71.8
	CEG	3	2.4	2.4	74.2
	MCC	1	.8	.8	75.0
	ALTORATH	2	1.6	1.6	76.6
	ARCHEN	1	.8	.8	77.4
	Siac	1	.8	.8	78.2
	IST- RAK Egypt	1	.8	.8	79.0
	Semaan	1	.8	.8	79.8
	Elkhereijiy Contracting Co.	1	.8	.8	80.6
	asc	1	.8	.8	81.5
	special work	1	.8	.8	82.3
	Jenan Real Estate	1	.8	.8	83.1
	Alrasheed	1	.8	.8	83.9
	Ghg	1	.8	.8	84.7

	EL-SHOROUQ ENGINEERING CONSULTANTS	1	.8	.8	85.5
	مكتب نغيمش الاحمدي للاستشارات	1	.8	.8	86.3
	Faculty of Engineering Mattaria	1	.8	.8	87.1
	Barling construction	1	.8	.8	87.9
	Suliman Alrajhi educational & development ci.	1	.8	.8	88.7
	GDMW	1	.8	.8	89.5
	شركة دار التصاميم المعمارية	1	.8	.8	90.3
	Cube consultants	1	.8	.8	91.1
	Andalusia architects	1	.8	.8	91.9
	Arab contractors	1	.8	.8	92.7
	Allam sons	1	.8	.8	93.5
	Loughborough University	1	.8	.8	94.4
	Dubai Municipality	1	.8	.8	95.2
	Iproplan	1	.8	.8	96.0
	N.A.	5	4.0	4.0	100.0
	Total	124	100.0	100.0	

Country

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Egypt	38	30.6	30.6	30.6
	Saudi Arabia	56	45.2	45.2	75.8
	Kuwait	1	.8	.8	76.6
	UAE	5	4.0	4.0	80.6
	USA	3	2.4	2.4	83.1
	Canada	1	.8	.8	83.9
	Iraq	3	2.4	2.4	86.3
	Palestine	1	.8	.8	87.1
	Germany	1	.8	.8	87.9
	India	1	.8	.8	88.7
	Czech Republic	3	2.4	2.4	91.1
	Qatar	4	3.2	3.2	94.4
	Philippines	2	1.6	1.6	96.0
	Libya	1	.8	.8	96.8
	Syria	2	1.6	1.6	98.4
	U. K	2	1.6	1.6	100.0
	Total	124	100.0	100.0	

Company business Field					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Design firm/Consultant	63	50.8	50.8	50.8
	Contractor	42	33.9	33.9	84.7
	Government Engineering Department	6	4.8	4.8	89.5
	Independent Project Management office (PMO)	4	3.2	3.2	92.7
	Real-estate	1	.8	.8	93.5
	Owner	8	6.5	6.5	100.0
	Total	124	100.0	100.0	

Company influence area					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Regional	65	52.4	52.4	52.4
	International	59	47.6	47.6	100.0
	Total	124	100.0	100.0	

Does your company has experience in sustainable buildings field?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	63	50.8	50.8	50.8
	No	61	49.2	49.2	100.0
	Total	124	100.0	100.0	

If Yes, How many years?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	≥ 15 Yrs.	17	13.7	13.7	13.7
	5-15 Yrs.	32	25.8	25.8	39.5
	≤ 5 Yrs.	75	60.5	60.5	100.0
	Total	124	100.0	100.0	

Does your company has participated in any sustainable project certification process?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	54	43.5	43.5	43.5
	No	70	56.5	56.5	100.0
	Total	124	100.0	100.0	

Which rating system(s) your company went through?				
	Frequency	Percent	Valid Percent	Cumulative Percent

Valid	LEED	62	50.0	50.0	50.0
	BREEAM	4	3.2	3.2	53.2
	Green Star	6	4.8	4.8	58.1
	Estedama	4	3.2	3.2	61.3
	GSAS	4	3.2	3.2	64.5
	HQE	3	2.4	2.4	66.9
	SBTool	3	2.4	2.4	69.4
	DGNB	2	1.6	1.6	71.0
	Green Globes	4	3.2	3.2	74.2
	Dubai municipality	1	.8	.8	75.0
	CASBEE	1	.8	.8	75.8
	Non	30	24.2	24.2	100.0
	Total	124	100.0	100.0	

Does your company has experience in Building Information Modeling (BIM) field?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	69	55.6	55.6	55.6
	No	55	44.4	44.4	100.0
	Total	124	100.0	100.0	

If Yes, How many years?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	≥ 10 Yrs.	12	9.7	9.7	9.7
	5-10 Yrs.	21	16.9	16.9	26.6
	≤ 5 Yrs.	39	31.5	31.5	58.1
	Non	52	41.9	41.9	100.0
	Total	124	100.0	100.0	

Which BIM software your company use in Architectural Modeling?

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Revit	75	60.5	60.5	60.5
	Sketchup	17	13.7	13.7	74.2
	ArchiCAD	23	18.5	18.5	92.7
	Bentley	1	.8	.8	93.5
	Non	8	6.5	6.5	100.0
	Total	124	100.0	100.0	

For which purpose your company using BIM approach?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	3D Modeling	10	8.1	8.1	8.1
	3D Modeling & Information Modeling	12	9.7	9.7	17.7
	Structural analysis	5	4.0	4.0	21.8
	Coordination between disciplines	26	21.0	21.0	42.7
	Energy Performance Analysis	3	2.4	2.4	45.2
	All above	25	20.2	20.2	65.3
	Non	43	34.7	34.7	100.0
	Total	124	100.0	100.0	

Does your company conduct building performance analysis (BPA) calculations?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	35	28.2	28.2	28.2
	No	89	71.8	71.8	100.0
	Total	124	100.0	100.0	

Which BIM-based software/application or cloud that your company are using for building performance simulation (BPS)?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Revit	36	29.0	29.0	29.0
	Revit and Green Building Studio	5	4.0	4.0	33.1
	Revit and Insight 360	5	4.0	4.0	37.1
	eQuest	1	.8	.8	37.9
	Design builder	1	.8	.8	38.7
	Ecotect	1	.8	.8	39.5
	Non	75	60.5	60.5	100.0
	Total	124	100.0	100.0	

Does your company consider building performance simulation (BPS) or manual calculation as an integral part in design procedure?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	33	26.6	26.6	26.6
	No	11	8.9	8.9	35.5
	My company is not Design firm	21	16.9	16.9	52.4
	I don't know	59	47.6	47.6	100.0
	Total	124	100.0	100.0	

Does your company consider building performance simulation (BPS) or manual calculation as an integral part in feasibility study procedure?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	25	20.2	20.2	20.2
	No	15	12.1	12.1	32.3
	My company is not responsible for preparing feasibility studies	26	21.0	21.0	53.2
	I don't know	58	46.8	46.8	100.0
	Total	124	100.0	100.0	

Your company may conduct building performance simulation (BPS) or manual calculation for the following reason(s):					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Just upon owner request	42	33.9	33.9	33.9
	(BPA) is a mandatory in my country laws (municipality regulations, License requirements,..atc)	2	1.6	1.6	35.5
	(BPA) is a part of company policy as an environmental responsibility	11	8.9	8.9	44.4
	To ensure achieving project goals	1	.8	.8	45.2
	Following progress	1	.8	.8	46.0
	I don't know	67	54.0	54.0	100.0
	Total	124	100.0	100.0	

Your company has a commitment to one or more of the following initiatives:					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Architecture 2030 challenge	15	12.1	12.1	12.1
	United Nations Environment Programme - sustainable buildings and climate initiative (UNEP-SBCI)	4	3.2	3.2	15.3
	My company just has a general interest in environmental issues	39	31.5	31.5	46.8
	Local regulations	1	.8	.8	47.6
	I don't know	65	52.4	52.4	100.0
	Total	124	100.0	100.0	

Does your company conduct Energy Optimization studies in concept design phase?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	40	32.3	32.3	32.3
	No	84	67.7	67.7	100.0
	Total	124	100.0	100.0	

If Yes, which method are you company using for energy optimization studies?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Computerized software and plugins	19	15.3	15.3	15.3
	With cooperation by specialist party	16	12.9	12.9	28.2
	Manual tries according to Architects experience	9	7.3	7.3	35.5
	N.A.	80	64.5	64.5	100.0
	Total	124	100.0	100.0	

Which software/plugins your company are using for energy optimization studies?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Revit	39	31.5	31.5	31.5
	Grasshopper (Ladybug, Honeybee, Octopus.....atc)	2	1.6	1.6	33.1
	Dynamo	1	.8	.8	33.9
	Design builder	1	.8	.8	34.7
	N.A.	81	65.3	65.3	100.0
	Total	124	100.0	100.0	

To what extent your company experienced that software/plugins are beneficial for design output?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Somewhat helpful	23	18.5	18.5	18.5
	Extremely beneficial	29	23.4	23.4	41.9
	Not helpful at all	3	2.4	2.4	44.4
	I don't know	69	55.6	55.6	100.0
	Total	124	100.0	100.0	

How does your company evaluate the Accuracy of simulation results?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Just give a feasible perception	12	9.7	9.7	9.7
	Give confusing results	4	3.2	3.2	12.9
	Good	34	27.4	27.4	40.3
	Excellent	10	8.1	8.1	48.4
	N.A.	64	51.6	51.6	100.0
	Total	124	100.0	100.0	

Which environmental studies your company take in consideration before simulation run?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Building orientation	10	8.1	8.1	8.1
	Mass study	3	2.4	2.4	10.5
	Solar study	4	3.2	3.2	13.7
	Thermal Properties of envelope materials	3	2.4	2.4	16.1
	Wind study	2	1.6	1.6	17.7
	Potential renewable energy saving	1	.8	.8	18.5
	All Above	36	29.0	29.0	47.6
	N.A.	65	52.4	52.4	100.0
	Total	124	100.0	100.0	

In your company, building performance analysis (BPA) team is:					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Mechanical engineer and data entry	4	3.2	3.2	3.2
	Architect with data entry	15	12.1	12.1	15.3
	Architect, Mechanical and electrical engineer and they are already having another task	19	15.3	15.3	30.6
	A separate team which have professionals in the building performance analysis and sustainability	13	10.5	10.5	41.1
	Third party	1	.8	.8	41.9
	N.A.	72	58.1	58.1	100.0
	Total	124	100.0	100.0	

Does your company verify the simulation results of building performance analysis (BPA) by an expert?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	17	13.7	13.7	13.7
	No	18	14.5	14.5	28.2
	Sometimes	22	17.7	17.7	46.0
	N.A.	67	54.0	54.0	100.0
	Total	124	100.0	100.0	

If there are deferential in results between traditional method vs BIM-based simulation, what are your company see the main reason(s)?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	A difficult to cover the amount of data required in simulation software	11	8.9	8.9	8.9
	Lack of staff experience and awareness of simulation requirement	10	8.1	8.1	16.9
	Traditional method ignores some of measurement factors	8	6.5	6.5	23.4
	BIM-based simulation need a complicated framework	8	6.5	6.5	29.8
	The maturity of the BIM software itself has not been proven yet	3	2.4	2.4	32.3
	All Above	14	11.3	11.3	43.5
	N.A.	70	56.5	56.5	100.0
	Total	124	100.0	100.0	

To what extent your company believe that the sustainable BIM-based software has improved in the last 3 years?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	In the middle of the way	23	18.5	18.5	18.5
	Significantly improved	26	21.0	21.0	39.5
	Nothing noteworthy	9	7.3	7.3	46.8
	I don't know	66	53.2	53.2	100.0
	Total	124	100.0	100.0	

Does your company intent to adopt BIM-based sustainable building performance simulation (BPS) in the near future?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	38	30.6	30.6	30.6
	No	12	9.7	9.7	40.3
	These subject still under study	18	14.5	14.5	54.8
	I don't know	56	45.2	45.2	100.0
	Total	124	100.0	100.0	

What is your company's vision toward the future of BIM-based sustainable building performance analysis approach?					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Future can be handled without using these approach	9	7.3	7.3	7.3
	Need at least a decade to be strong method	18	14.5	14.5	21.8
	Likely to be strongly promoted	41	33.1	33.1	54.8
	I don't know	56	45.2	45.2	100.0
	Total	124	100.0	100.0	

A.2 Reliability analysis

Table A-2: Reliability Statics – Cronbach's Alpha

Reliability Statistics		Cases		N	%
Cronbach's Alpha	N of Items		Valid	**124**	**100**
			Excluded[a]	**0**	**0**
.915	26		Total	124	100
		a. Listwise deletion based on all variables in the procedure.			

Table A-2: Reliability Items Statics

Item-Total Statistics				
	Scale Mean if Item Deleted	Scale Variance if Item Deleted	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Does your company has experience in sustainable buildings field?	90.64	812.737	.575	.914
If Yes, How many years?	89.66	815.673	.319	.915
Does your company has participated in any sustainable project certification process?	90.56	817.370	.416	.915
Which rating system(s) your company went through? (You can choose more than one)	87.07	693.596	.414	.931
Does your company has experience in Building Information Modeling (BIM) field?	90.69	810.445	.660	.914
If Yes, How many years?	89.07	795.043	.599	.913
Which BIM software your company use in Architectural Modeling? (You can choose more than one)	90.27	784.379	.567	.912
For which purpose your company using BIM approach? (You can choose more than one)	86.02	760.471	.369	.917

Does your company conduct building performance analysis (BPA) calculations?	90.41	814.537	.570	.915
Which BIM-based software/application or cloud that your company are using for building performance simulation (BPS)? (You can choose more than one)	85.41	644.634	.783	.910
Does your company consider building performance simulation (BPS) or manual calculation as an integral part in design procedure?	89.27	774.233	.756	.910
Does your company consider building performance simulation (BPS) or manual calculation as an integral part in feasibility study procedure?	89.19	777.681	.762	.910
Your company may conduct building performance simulation (BPS) or manual calculation for the following reason(s):(You can choose more than one)	88.18	734.050	.714	.908
Your company has a commitment to one or more of the following initiatives:(You can choose more than one)	88.35	768.537	.746	.910
Does your company conduct Energy Optimization studies in concept design phase?	90.45	810.884	.686	.914
If Yes, which method are you company using for energy optimization studies?	87.63	740.951	.743	.908
Which software/plugins your company are using for energy optimization studies? (You can choose more than one)	88.46	747.112	.774	.908

To what extent your company experienced that software/plugins are beneficial for design output?	89.18	770.863	.827	.909
How does your company evaluate the Accuracy of simulation results?	88.24	774.087	.719	.910
Which environmental studies your company take in consideration before simulation run? (You can choose more than one)	83.81	740.808	.504	.914
In your company, building performance analysis (BPA) team is:	87.45	750.591	.826	.908
Does your company verify the simulation results of building performance analysis (BPA) by an expert?	89.01	781.244	.758	.911
If there are deferential in results between traditional method vs BIM-based simulation, what are your company see the main reason(s)? (You can choose more than one)	86.68	743.798	.687	.909
To what extent your company believe that the sustainable BIM-based software has improved in the last 3 years?	89.18	771.676	.829	.909
Does your company intent to adopt BIM-based sustainable building performance simulation (BPS) in the near future?	89.39	774.288	.732	.910
What is your company's vision toward the future of BIM-based sustainable building performance analysis approach?	88.97	796.503	.610	.913

A.3 Bivariate Correlations Analysis

Table A-3: Correlations – Group one

			Does your company has experience in sustainable buildings field?	If Yes, How many years?	Does your company has participated in any sustainable project certification process?	Which rating system(s) your company went through?(You can choose more than one)
Kendall's tau_b	Does your company has experience in sustainable buildings field?	Correlation Coefficient	1.000	.677**	.669**	.538**
		Sig. (2-tailed)	.	.000	.000	.000
		N	124	124	124	124
	If Yes, How many years?	Correlation Coefficient	.677**	1.000	.566**	.415**
		Sig. (2-tailed)	.000	.	.000	.000
		N	124	124	124	124
	Does your company has participated in any sustainable project certification process?	Correlation Coefficient	.669**	.566**	1.000	.450**
		Sig. (2-tailed)	.000	.000	.	.000
		N	124	124	124	124
	Which rating system(s) your company went through?(You can choose more than one)	Correlation Coefficient	.538**	.415**	.450**	1.000
		Sig. (2-tailed)	.000	.000	.000	.
		N	124	124	124	124

**. Correlation is significant at the 0.01 level (2-tailed).

Table A-4: Correlations - Group Two

			Does your company has experience in Building Information Modeling (BIM) field?	If Yes, How many years?	Which BIM software your company use in Architectural Modeling? (You can choose more than one)	For which purpose your company using BIM approach? (You can choose more than one)
Kendall's tau_b	Does your company has experience in Building Information Modeling (BIM) field?	Correlation Coefficient	1.000	.810**	.705**	.497**
		Sig. (2-tailed)	.	.000	.000	.000
		N	124	124	124	124
	If Yes, How many years?	Correlation Coefficient	.810**	1.000	.617**	.389**
		Sig. (2-tailed)	.000	.	.000	.000
		N	124	124	124	124
	Which BIM software your company use in Architectural Modeling? (You can choose more than one)	Correlation Coefficient	.705**	.617**	1.000	.514**
		Sig. (2-tailed)	.000	.000	.	.000
		N	124	124	124	124
	For which purpose your company using BIM approach? (You can choose more than one)	Correlation Coefficient	.497**	.389**	.514**	1.000
		Sig. (2-tailed)	.000	.000	.000	.
		N	124	124	124	124

**. Correlation is significant at the 0.01 level (2-tailed).

Table A-5: Correlations - Group Three

			Software/plugins are beneficial for design output?	Accuracy of simulation results?	(BPA) team is:	Does your company verify (BPA) by an expert?	reason(s) of results deferential
Kendall's tau_b	To what extent your company experienced that software/plugins are beneficial for design output?	Correlation Coefficient	1.000	.776**	.707**	.665**	.707**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	124	124	124	124	124
	How does your company evaluate the Accuracy of simulation results?	Correlation Coefficient	.776**	1.000	.674**	.659**	.629**
		Sig. (2-tailed)	.000	.	.000	.000	.000
		N	124	124	124	124	124
	In your company, building performance analysis (BPA) team is:	Correlation Coefficient	.707**	.674**	1.000	.697**	.669**
		Sig. (2-tailed)	.000	.000	.	.000	.000
		N	124	124	124	124	124
	Does your company verify the simulation results of building performance analysis (BPA) by an expert?	Correlation Coefficient	.665**	.659**	.697**	1.000	.687**
		Sig. (2-tailed)	.000	.000	.000	.	.000
		N	124	124	124	124	124
	If there are deferential in results between traditional method vs BIM-based simulation, what are your company see the main reason(s)? (You can choose more than one)	Correlation Coefficient	.707**	.629**	.669**	.687**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	124	124	124	124	124

**. Correlation is significant at the 0.01 level (2-tailed).

Table A-6: Correlations - Group Four

			Does your company conduct (BPA) calculations?	Which BIM-based software your company are using for (BPS)?	(BPS) or manual calculation as an integral part in design procedure?	(BPS) or manual calculation as an integral part in feasibility study procedure?	Your company may conduct (BPS) or manual calculation for the following reason(s)
Kendall's tau_b	Does your company conduct building performance analysis (BPA) calculations?	Correlation Coefficient	1.000	.605**	.513**	.526**	.429**
		Sig. (2-tailed)	.	.000	.000	.000	.000
		N	124	124	124	124	124
	Which BIM-based software/application or cloud that your company are using for building performance simulation (BPS)?(You can choose more than one)	Correlation Coefficient	.605**	1.000	.657**	.649**	.649**
		Sig. (2-tailed)	.000	.	.000	.000	.000
		N	124	124	124	124	124
	Does your company consider building performance simulation (BPS) or manual calculation as an integral part in design procedure?	Correlation Coefficient	.513**	.657**	1.000	.791**	.625**
		Sig. (2-tailed)	.000	.000	.	.000	.000
		N	124	124	124	124	124
	Does your company consider building performance simulation (BPS) or manual calculation as an integral part in feasibility study procedure?	Correlation Coefficient	.526**	.649**	.791**	1.000	.634**
		Sig. (2-tailed)	.000	.000	.000	.	.000
		N	124	124	124	124	124
	Your company may conduct building performance simulation (BPS) or manual calculation for the following reason(s):(You can choose more than one)	Correlation Coefficient	.429**	.649**	.625**	.634**	1.000
		Sig. (2-tailed)	.000	.000	.000	.000	.
		N	124	124	124	124	124

**. Correlation is significant at the 0.01 level (2-tailed).

Table A-7: Correlations - Group Five

			Does your company conduct Energy Optimization studies in concept design phase?	If Yes, which method are you company using for energy optimization studies?	Which software/plugins your company are using for energy optimization studies? (You can choose more than one)
Kendall's tau_b	Does your company conduct Energy Optimization studies in concept design phase?	Correlation Coefficient	1.000	.833**	.666**
		Sig. (2-tailed)	.	.000	.000
		N	124	124	124
	If Yes, which method are you company using for energy optimization studies?	Correlation Coefficient	.833**	1.000	.712**
		Sig. (2-tailed)	.000	.	.000
		N	124	124	124
	Which software/plugins your company are using for energy optimization studies? (You can choose more than one)	Correlation Coefficient	.666**	.712**	1.000
		Sig. (2-tailed)	.000	.000	.
		N	124	124	124

**. Correlation is significant at the 0.01 level (2-tailed).

Table A-8: Correlations - Group Six

			To what extent your company believe that the sustainable BIM-based software has improved in the last 3 years?	Does your company intent to adopt BIM-based sustainable building performance simulation (BPS) in the near future?	What is your company's vision toward the future of BIM-based sustainable building performance analysis approach?
Kendall's tau_b	To what extent your company believe that the sustainable BIM-based software has improved in the last 3 years?	Correlation Coefficient	1.000	.682**	.618**
		Sig. (2-tailed)	.	.000	.000
		N	124	124	124
	Does your company intent to adopt BIM-based sustainable building performance simulation (BPS) in the near future?	Correlation Coefficient	.682**	1.000	.598**
		Sig. (2-tailed)	.000	.	.000
		N	124	124	124
	What is your company's vision toward the future of BIM-based sustainable building performance analysis approach?	Correlation Coefficient	.618**	.598**	1.000
		Sig. (2-tailed)	.000	.000	.
		N	124	124	124

**. Correlation is significant at the 0.01 level (2-tailed).

Appendix B. . Use Types and Categories

The following Table B-1 used for all related Building Design & Construction, Interior Design & Construction, and Neighborhood Development prerequisites and credits. Use types classified in categories.

Table B-1: Use Types

Category	Use type
Food retail	Supermarket
	Other food store with produce section
Community-serving retail	Convenience store
	Farmers market
	Hardware store
	Pharmacy
	Other retail
Services	Bank
	Family entertainment venue (e.g., theater, sports)
	Gym, health club, exercise studio
	Hair care
	Laundry, dry cleaner
	Restaurant, café, diner (excluding those with only drive-thru service)
Civic and community facilities	Adult or senior care (licensed)
	Child care (licensed)
	Community or recreation center
	Cultural arts facility (museum, performing arts)
	Education facility (e.g., K—12 school, university, adult education center, vocational school, community college)
	Government office that serves public on-site
	Medical clinic or office that treats patients
	Place of worship
	Police or fire station
	Post office
	Public library
	Public park
	Social services center
Community anchor uses (BD&C and ID&C only)	Commercial office (100 or more full-time equivalent jobs)
	Housing (100 or more dwelling units)

Adapted from Criterion Planners, INDEX neighborhood completeness indicator, 2005.

Appendix C. References of LEED v4 Categories

Integrative Process (IP) Referenced Standards

- IPp Integrated Project Planning and Design (healthcare only)
- None
- IPc Integrative Process
- ANSI Consensus National Standard Guide© 2.0 for Design and Construction of Sustain- able Buildings and Communities

Location and Transportation (LT) Referenced Standards

LTc LEED for Neighborhood Development Location

- None

LTc Sensitive Land Protection

- U.S. Department of Agriculture, U.S. Code of Federal Regulations Title 7, Volume 6, Parts 400 to 699, Section 657.5
- FEMA Flood Zone Designations
- U.S. Fish and Wildlife Service, List of Threatened and Endangered Species
- NatureServe Heritage Program, GH, G1, and G2 species and ecological communities

LTc High Priority Site

- U.S. Environmental Protection Agency, National Priority List
- U.S. Housing and Urban Development, Federal Empowerment Zone, Federal Enterprise Community, and Federal Renewal Community
- U.S. Department of Treasury, Community Development Financial Institutions Fund
- U.S. Department of Housing and Urban Development, Qualified Census Tracts and Difficult Development Areas

LTc Surrounding Density and Diverse Uses

- None

LTc Access to Quality Transit

- None

LTc Bicycle Facilities

- None

LTc Reduced Parking Footprint

- Institute of Transportation Engineers, Transportation Planning Handbook, 3rd edition, Tables 18-2 through 18-4

LTc Green Vehicles

- American Council for an Energy Efficient Economy (ACEEE) Green Book
- Society of Automotive Engineers, SAE Surface Vehicle Recommended Practice J1772, SAE Electric Vehicle Conductive Charge Coupler
- International Electro technical Commission 62196

Sustainable Sites (SS) Chapter Referenced Standards

SSp Construction Activity Pollution Prevention

- 2003 EPA Construction General Permit

SSp Environmental Site Assessment (Schools and Healthcare only)

- ASTM E1527—05 Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process
- ASTM E1903—11 Standard Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process
- 40 CFR Part 312: Standards and Practice for All Appropriate Inquiries; Final Rule

SSc Site Assessment

- ASTM E1527—05 Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process
- ASTM E1903—11 Standard Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process
- 40 CFR Part 312: Standards and Practice for All Appropriate Inquiries; Final Rule
- Natural Resources Conservation Service, web soil survey
- TR-55 initial water storage capacity

SSc Site Development - Protect or Restore Habitat

- U.S. EPA ecoregions

- Land Trust Alliance accreditation
- Natural Resources Conservation Service, web soil survey
- Sustainable Sites Initiative

SSc Open Space

- None

SSc Rainwater Management

- U.S. EPA Technical Guidance on Implementing the Rainwater Runoff Requirements for Federal Projects under Section 438 of the Energy Independence and Security Act

SSc Heat Island Reduction

- ASTM Standards E903 and E892
- Cool Roof Rating Council Standard (CRRC-1)

SSc Light Pollution Reduction

- Illuminating Engineering Society and International Dark Sky Association (IES/IDA) Mod- el Lighting Ordinance User Guide and IES TM-15-11, Addendum A

SSc Site Master Plan (Schools only)

- None

SSc Tenant Design and Construction Guidelines (Core and Shell only)

- None

SSc Places of Respite (Healthcare only)

- 2010 FGI Guidelines for Design and Construction of Health Care Facilities

SSc Direct Exterior Access (Healthcare only)

- None

SSc Joint Use of Facilities (Schools only)

- None

Water Efficiency (WE) Referenced Standards

WEp Outdoor Water Use Reduction

- None

WEp Indoor Water Use Reduction

- Energy Policy Act (EPAct) of 1992 and as amended
- EPAct 2005
- International Association of Plumbing and Mechanical Officials Publication IAPMO / ANSI UPC 1-2006, Uniform Plumbing Code 2006, Section 402.0, Water-Conserving Fixtures and Fittings
- International Code Council, International Plumbing Code 2006, Section 604, Design of Building Water Distribution System
- ENERGY STAR
- Consortium for Energy Efficiency
- IgCC/ASHRAE 189.1

WEp Building-level Water Metering

- None

WEc Outdoor Water Use Reduction

- None

WEc Indoor Water Use Reduction

- Energy Policy Act (EPAct) of 1992 and as amended
- EPAct 2005
- International Association of Plumbing and Mechanical Officials Publication IAPMO / ANSI UPC 1-2006, Uniform Plumbing Code 2006, Section 402.0, Water-Conserving Fixtures and Fittings
- International Code Council, International Plumbing Code 2006, Section 604, Design of Building Water Distribution System
- ENERGY STAR
- Consortium for Energy Efficiency
- Energy Policy Act (EPAct) of 1992 and as amended
- IgCC/ASHRAE 189.1

WEc Cooling Tower Water Use

- None

WEc Water Metering

- None

Energy and Atmosphere (EA) Referenced Standards

EAp Fundamental Commissioning and Verification

- ASHRAE Guideline 0–2005, The Commissioning Process
- ASHRAE Guideline 1.1–2007, HVAC&R Technical Requirements for the Commissioning Process
- NIBS Guideline 3–2012, Exterior Enclosure Technical Requirements for the Commissioning Process

EAp Minimum Energy Performance

- ASHRAE 90.1–2010
- ASHRAE 50% Advanced Energy Design Guides
- Advanced Buildings Core Performance Guide
- COMNET Commercial Buildings Energy Modeling Guidelines

EAp Building-level Energy Metering

- American National Standards Institute, ANSI C12.20, Class 0.2 (±0.2)
- American National Standards Institute, ANSI B109
- EN Standard, EN-1434: Thermal energy (Btu meter or heat meter)

EAp Fundamental Refrigerant Management

- U.S. EPA Clean Air Act, Title VI, Section 608, Refrigerant Recycling Rule

EAc Enhanced Commissioning

- ASHRAE Guideline 0–2005, The Commissioning Process
- ASHRAE Guideline 1.1–2007, HVAC&R Technical Requirements for the Commissioning Process
- NIBS Guideline 3–2012, Exterior Enclosure Technical Requirements for the Commissioning Process

EAc Optimize Energy Performance

- ASHRAE 90.1–2010
- ASHRAE 50% Advanced Energy Design Guides

- COMNET Commercial Buildings Energy Modeling Guidelines

EAc Advanced Energy Metering

- None

EAc Demand Response

- None

EAc Renewable Energy Production

- Center for Resource Solutions Green-e Program
- Commercial Building Energy Consumption Survey (CBECS)

EAc Enhanced Refrigerant Management

- None

EAc Green Power and Carbon Offsets

- Green-e Energy and Green-e Climate
- Commercial Building Energy Consumption Survey (CBECS)
- Building Owners and Managers Association (BOMA)
- ENERGY STAR Portfolio Manager: Methodology for Greenhouse Gas Inventory and Tracking Calculations
- Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2010. Annex 2 Methodology and Data for Estimating CO2 Emissions from Fossil Fuel Combustion
- 2006 IPCC Guidelines for National Greenhouse Gas Inventories
- eGRID2012 Version 1.0—U.S. Environmental Protection Agency
- WRI-WBCSD Greenhouse Gas Protocol

Materials and Resources (MR) Referenced Standards

MRp Storage and Collection of Recyclables

- None

MRp Construction and Demolition Waste Management Planning

- European Commission Waste Framework Directive 2008/98/EC
- European Commission Waste Incineration Directive 2000/76/EC
- EN 303-1—1999/A1—2003, Heating boilers with forced draught burners,

Terminology, general requirements, testing and marking

- EN 303-2—1998/A1—2003, Heating boilers with forced draught burners, Special requirements for boilers with atomizing oil burners
- EN 303-3—1998/AC—2006, Gas-fired central heating boilers, Assembly comprising a boiler body and a forced draught burner
- EN 303-4—1999, Heating boilers with forced draught burners, Special requirements for boilers with forced draught oil burners with outputs up to 70 kW and a maximum operating pressure of 3 bar, Terminology, special requirements, testing and marking
- EN 303-5—2012, Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW
- EN 303-6—2000, Heating boilers with forced draught burners, Specific requirements for the domestic hot water operation of combination boilers with atomizing oil burners of nominal heat input not exceeding 70 kW
- EN 303-7—2006, Gas-fired central heating boilers equipped with a forced draught burner of nominal heat output not exceeding 1000 kW

MRp PBT Source Reduction--Mercury (Healthcare only)

- Guidelines for the Design and Construction of Health Care Facilities, 2010 Edition
- ISO-11143, Dentistry, Amalgam Separators
- ENERGY STAR
- U.S. Department of Energy ENERGY STAR Qualified Light Bulbs, 2009 Partner Resource Guide
- Toxicological Effects of Methylmercury

MRc Building Life Cycle Impact Reduction

- ISO 14044–2006, Environmental management, Life cycle assessment requirements, and guidelines
- National Register of Historic Places
- Secretary of Interior’s Standards for the Treatment of Historic Properties

MRc Building Product Disclosure and Optimization - Environmental

Product Declarations

- ISO 14021–1999, Environmental labels and declarations—Self Declared Claims (Type II Environmental Labeling)
- ISO 14025–2006, Environmental labels and declarations (Type III Environmental Declarations—Principles and Procedures)
- ISO 14040–2006, Environmental management, Life cycle assessment principles, and frameworks
- ISO 14044–2006, Environmental management, Life cycle assessment requirements, and guidelines
- EN 15804—2012 Sustainability of construction works, Environmental product declarations, Core rules for the product category of construction products
- ISO 21930–2007 Sustainability in building construction—Environmental declaration of building products
- Guides for the Use of Environmental Marketing Claims, 16 CFR 260.7 (e)

MRc Building Product Disclosure and Optimization - Sourcing of Raw Materials

- Global Reporting Initiative (GRI) Sustainability Report
- Organization for Economic Co-operation and Development (OECD) Guidelines for Multinational Enterprises
- U.N. Global Compact, Communication of Progress
- ISO 26000—2010 Guidance on Social Responsibility
- Forest Stewardship Council
- Sustainable Agriculture Network
- The Rainforest Alliance
- ASTM Test Method D6866
- ISO 14021–1999, Environmental labels and declarations—Self Declared Claims (Type II Environmental Labeling)

MRc Building Product Disclosure and Optimization - Material Ingredients

- Chemical Abstracts Service
- Health Product Declaration
- Cradle-to-Cradle® Certified Products Program
- Registration, Evaluation, Authorization and Restriction of Chemicals (REACH)
- GreenScreen

MRc Construction and Demolition Waste Management

- Certification of Sustainable Recyclers
- European Commission Waste Framework Directive 2008/98/EC
- European Commission Waste Incineration Directive 2000/76/EC
- EN 303-1—1999/A1—2003, Heating boilers with forced draught burners, Terminology, general requirements, testing and marking
- EN 303-2—1998/A1—2003, Heating boilers with forced draught burners, Special requirements for boilers with atomizing oil burners
- EN 303-3—1998/AC—2006, Gas-fired central heating boilers, Assembly comprising a boiler body and a forced draught burner
- EN 303-4—1999, Heating boilers with forced draught burners, Special requirements for boilers with forced draught oil burners with outputs up to 70 kW and a maximum operating pressure of 3 bar, Terminology, special requirements, testing and marking
- EN 303-5—2012, Heating boilers for solid fuels, manually and automatically stoked, nominal heat output of up to 500 kW
- EN 303-6—2000, Heating boilers with forced draught burners, Specific requirements for the domestic hot water operation of combination boilers with atomizing oil burners of nominal heat input not exceeding 70 kW
- EN 303-7—2006, Gas-fired central heating boilers equipped with a forced draught burner of nominal heat output not exceeding 1000 kW

MRc PBT Source Reduction--Mercury (Healthcare only)

- None

MRc PBT Source Reduction--Lead, Cadmium & Copper (Healthcare only)

- ASTM B813 for copper flux
- ASTM B828, Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings
- California AB1953 standard for lead water pipes used to convey water for human consumption
- GreenSeal
- 2002 National Electric Code requirements for removal and disposal of disconnected wires with lead stabilizers

MRc Furniture and Medical Furnishings (Healthcare only)

- Restriction of the Use of Certain Hazardous Substances of the European Union Directive (EU RoHS)
- ANSI/BIFMA M7.1–2011
- ANSI/BIFMA e3–2011
- ISO 14025–2006, Environmental labels and declarations (Type III Environmental Declarations—Principles and Procedures)
- ISO 14040–2006, Environmental management, Life cycle assessment principles, and frameworks
- ISO 14044–2006, Environmental management, Life cycle assessment requirements, and guidelines
- ISO 21930–2007 Sustainability in building construction—Environmental declaration of building products
- ISO 14021–1999, Environmental labels and declarations—Self Declared Claims (Type II Environmental Labeling)

MRc Design for Flexibility (Healthcare only)

Indoor Environmental Quality (EQ) Referenced Standards

EQp Minimum Indoor Air Quality Performance

- ASHRAE Standard 62.1–2010: Ventilation for Acceptable Indoor Air Quality
- Comité Européen de Normalisation (CEN) Standard EN 15251–2007: Indoor environ- mental input parameters for design and assessment of

energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics

- Comité Européen de Normalisation (CEN) Standard EN 13779–2007: Ventilation for nonresidential buildings, Performance requirements for ventilation and room conditioning systems
- Chartered Institution of Building Services Engineers (CIBSE) Applications Manual AM10, March 2005, Natural Ventilation in Nondomestic Buildings
- ASHRAE Standard 170–2008: Ventilation of Health Care Facilities
- 2010 FGI Guidelines for Design and Construction of Health Care Facilities

EQp Environmental tobacco smoke control

- Standard Test Method for Determining Air Leakage Rate by Fan Pressurization, ASTM E779-03: Indoor Air Quality
- Standard Test Methods for Determining Airtightness of Buildings Using an Orifice Blower Door, ASTM E1827-11
- Nondestructive testing, Leak testing—Criteria for method and technique selection, CEN Standard EN 1779—1999
- Nondestructive testing, Leak testing, Tracer gas method, CEN Standard EN 13185— 2001
- Nondestructive testing, Leak testing, Calibration of reference leaks for gases, CEN Standard EN 13192—2001
- RESNET Standards
- ENERGY STAR Multifamily Testing Protocol

EQp Minimum Acoustic Performance (Schools only)

- AHRI Standard 885–2008, Procedure for Estimating Occupied Space Sound Levels in the Application of Air Terminals and Air Outlets
- American National Standards Institute (ANSI)/ASHRAE Standard S12.60-2010, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools
- 2011 HVAC Applications, ASHRAE Handbook, Chapter 48, Noise and Vibration Control

- NRC-CNRC Construction Technology Update No. 51, Acoustic Design of Rooms for Speech, 2002t

EQc Enhanced Indoor Air Quality Strategies

- ASHRAE Standard 52.2–2007
- CEN Standard EN 779–2002
- Chartered Institution of Building Services Engineers (CIBSE) Applications Manual AM10, March 2005, Natural Ventilation in Nondomestic Buildings
- Chartered Institution of Building Services Engineers (CIBSE) Applications Manual 13, 2000
- National Ambient Air Quality Standards (NAAQS)

EQc Low-Emitting materials

- California Department of Public Health (CDPH) Standard Method for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environ- mental Chambers, v. 1.1–2010
- ISO 17025
- ISO Guide 65
- German AgBB Testing and Evaluation Scheme (2010)
- ISO 16000-3:2011- Indoor air -- Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air Active sampling method
- ISO 16000-6:2011- Indoor air -- Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID
- ISO 16000-7:2007- Indoor air -- Part 7: Sampling strategy for determination of airborne asbestos fiber concentrations
- ISO 16000-11:2006- Indoor air -- Part 11: Determination of the emission of volatile organic compounds from building products and furnishing, Sampling, storage of samples and preparation of test specimens
- South Coast Air Quality Management District (SCAQMD) Rule 1168

- South Coast Air Quality Management District (SCAQMD) Rule 1113
- European Decopaint Directive
- Canadian VOC Concentration Limits for Architectural Coatings
- Hong Kong Air Pollution Control Regulation
- California Air Resources Board (CARB) 93120 Airborne Toxic Control Measure (ATCM) for formaldehyde emissions from composite wood products
- ANSI/BIFMA M7.1 Standard Test Method for Determining VOC Emissions from Office Furniture Systems, Components and Seating
- ANSI/BIFMA e3–2011 Furniture Sustainability Standard
- NIOSH, Asphalt Fume Exposures During the Application of Hot Asphalt to Roofs, Publication No. 2003-112
- ISO 4224 Ambient air Determination of carbon monoxide Nondispersive infrared spectrometric method
- ISO 7708 Air quality Particle size fraction definitions for health-related sampling
- ISO 13964 Air quality Determination of ozone in ambient air Ultraviolet photometric method
- U.S. EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air, IP-1: Volatile Organic Compounds, IP-3: Carbon Monoxide and Carbon Dioxide, IP-6: Formaldehyde and other aldehydes/ketones, IP-10 Volatile Organic Compounds
- U.S. EPA Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air, TO-1: Volatile Organic Compounds, TO-11: Formaldehyde, TO-15: Volatile Organic Compounds, TO-17: Volatile Organic Compounds
- ASTM D5197–09e1 Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology)
- ASTM D5149–02(2008) Standard Test Method for Ozone in the Atmosphere: Continuous Measurement by Ethylene Chemiluminescence

EQc Indoor Air Quality Assessment

- ASTM D5197–09e1 Standard Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology)
- ISO 16000-3:2011- Indoor air -- Part 3: Determination of formaldehyde and other carbonyl compounds in indoor air and test chamber air -- Active sampling method
- ISO 16000-6:2011- Indoor air -- Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS or MS-FID
- ASTM D5149–02(2008) Standard Test Method for Ozone in the Atmosphere: Continuous Measurement by Ethylene Chemiluminescence
- ISO 4224 Ambient air Determination of carbon monoxide Nondispersive infrared spectrometric method
- ISO 7708 Air quality Particle size fraction definitions for health-related sampling
- ISO 13964 Air quality Determination of ozone in ambient air—Ultraviolet photometric method
- U.S. EPA Compendium of Methods for the Determination of Air Pollutants in Indoor Air, IP-1: Volatile Organic Compounds, IP-3: Carbon Monoxide and Carbon Dioxide, IP-6: Formaldehyde and other aldehydes/ketones, IP-10 Volatile Organic Compounds
- U.S. EPA Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air, TO-1: Volatile Organic Compounds, TO-11: Formaldehyde, TO-15: Volatile Organic Compounds, TO-17: Volatile Organic Compounds
- California Department of Public Health (CDPH) Standard Method for the Testing and Evaluation of Volatile Organic Chemical Emissions from Indoor Sources Using Environ- mental Chambers, v. 1.1–2010

EQc Thermal Comfort

- 2011 HVAC Applications, ASHRAE Handbook, Chapter 48, Noise and

Vibration Control

- Comité Européen de Normalisation (CEN) Standard EN 15251–2007: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics
- ASHRAE Standard 55–2010, Thermal Environmental Conditions for Human Occupancy
- The Lighting Handbook, 10th edition, Illuminating Engineering Society of North America
- IES Lighting Measurements (LM) 83-12, Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)
- Windows and Offices: A Study of Office Worker Performance and the Indoor Environment
- ANSI S1.4, Performance Measurement Protocols for Commercial Buildings
- 2010 Noise and Vibration Guidelines for Health Care Facilities

EQc Interior Lighting

- The Lighting Handbook, 10th edition, Illuminating Engineering Society of North America
- IES Lighting Measurements (LM) 83-12, Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)
- Windows and Offices: A Study of Office Worker Performance and the Indoor Environment
- ANSI S1.4, Performance Measurement Protocols for Commercial Buildings
- 2010 Noise and Vibration Guidelines for Health Care Facilities

EQc Daylight

- IES Lighting Measurements (LM) 83-12, Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)
- The Lighting Handbook, 10th edition, Illuminating Engineering Society of North America
- Windows and Offices: A Study of Office Worker Performance and the

Indoor Environment

- ANSI S1.4, Performance Measurement Protocols for Commercial Buildings
- 2010 Noise and Vibration Guidelines for Health Care Facilities

EQc Quality Views

- Windows and Offices: A Study of Office Worker Performance and the Indoor Environment
- ANSI S1.4, Performance Measurement Protocols for Commercial Buildings
- 2010 Noise and Vibration Guidelines for Health Care Facilities

EQc Acoustic Performance

- 2011 HVAC Applications, ASHRAE Handbook, Chapter 48, Noise and Vibration Control
- AHRI Standard 885–2008, Procedure for Estimating Occupied Space Sound Levels in the Application of Air Terminals and Air Outlets
- 2010 Noise and Vibration Guidelines for Health Care Facilities
- American National Standards Institute (ANSI)/ASHRAE Standard S12.60–2010, Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools
- 2010 FGI Guidelines for Design and Construction of Health Care Facilities.

Appendix D. Default Occupancy Counts

Because of the speculative nature of core and shell construction, a project team may not know the final occupant count during the LEED certification process. Core and Shell projects that do not have final occupancy counts must use the default occupancy counts provided in (Error! Reference source not found.). Projects that know the tenant occupancy must use the actual numbers, as long as the gross floor area per employee does not exceed the default occupancy numbers; a lower figure for gross floor area per occupant is acceptable. Default occupancy counts are provided for typical core and shell project types. For circumstances not covered below, provide documentation for comparable buildings' average gross floor area per occupant.

Table D-1: Default Occupancy Numbers

	Gross square feet per occupant		**Gross square meters per occupant**	
	Employees	**Transients**	**Employees**	**Transients**
General office	250	0	23	0
Retail, general	550	130	51	12
Retail or service (e.g., financial, auto)	600	130	56	12
Restaurant	435	95	40	9
Grocery store	550	115	51	11
Medical office	225	330	21	31
R&D or laboratory	400	0	37	0
Warehouse, distribution	2,500	0	232	0
Warehouse, storage	20,000	0	1860	0
Hotel	1,500	700	139	65
Educational, daycare	630	105	59	10
Educational, K–12	1,300	140	121	13
Educational, postsecondary	**2,100**	**150**	**195**	**14**

Sources:

ANSI/ASHRAE/IESNA Standard 90.1–2004 (Atlanta, GA, 2004).

2001 Uniform Plumbing Code (Los Angeles, CA)

California Public Utilities Commission, 2004–2005 Database for Energy Efficiency Resources (DEER) Update Study (2008).
California State University, Capital Planning, Design and Construction Section VI, Standards for Campus Development Programs (Long Beach, CA, 2002). City of Boulder Planning Department, Projecting Future Employment—How Much Space per Person (Boulder, 2002).
Metro, 1999 Employment Density Study (Portland, OR 1999).
American Hotel and Lodging Association, Lodging Industry Profile Washington, DC, 2008. LEED for Core & Shell Core Committee, personal communication (2003 - 2006).
LEED for Retail Core Committee, personal communication (2007) OWP/P, Medical Office Building Project Averages (Chicago, 2008). OWP/P, University Master Plan Projects (Chicago, 2008).
U.S. General Services Administration, Childcare Center Design Guide (Washington, DC,2003).
The Tables above may be used to determine occupancy for the following credits:

- LT Credit: Bicycle Facilities
- LT Credit: Reduced Parking Footprint
- WE Prerequisite: Indoor Water Use Reduction
- WE Credit: Indoor Water Use Reduction
- EA Prerequisite: Minimum Energy Performance
- EA Credit: Optimized Energy Performance
- EQ Prerequisite: Minimum Indoor Air Quality Performance
- EQ Credit: Enhanced Indoor Air Quality Strategies
- EQ Credit: Thermal Comfort EQ Credit: Daylight
- EQ Credit: Quality Views EQ Credit: Interior Lighting

The defaults provided above are based on gross floor area per occupant, not net or leasable floor area per occupant. Gross floor area is defined as the

sum of all areas on all floors of a building included within the outside faces of the exterior wall, including common areas, mechanical spaces, circulation areas, and all floor penetrations that connect one floor to another. To determine gross floor area, multiply the building footprint (in square feet or square meters) by the number of floors in the building. Projects with underground or structured parking may exclude that area from the calculation.

Appendix E. Retail Process Load Baselines

Table E-1: Commercial kitchen appliance prescriptive measures and baseline for energy cost budget (IP units)

	Baseline energy usage for energy modeling path				Levels for prescriptive path	
Appliance type	Fuel	Function	Baseline efficiency	Baseline idle rate	Prescriptive efficiency	Prescriptive idle rate
Broiler, underfired	Gas	Cooking	30%	16,000 Btu/h/ft^2 peak input	35%	12000 Btu/h/ft^2 peak input
combination ovens: steam mode (P = pan capacity)	elec	cooking	40% steam mode	0.37P+4.5 kW	50% steam mode	0.133P+0.6400 kW
combination ovens: steam mode	gas	cooking	20% steam mode	1,210P+35,810 BTU/h	38% steam mode	200P+6,511 BTU/h
combination ovens: convection mode	elec	cooking	65% convection mode	0.1P+1.5 kW	70% convection mode	0.080P+0.4989 kW
combination ovens: convection mode	gas	cooking	35% convection mode	322P+13,563 BTU/h	44% convection mode	150P+5,425 BTU/h
Convection oven, full- size	Elec	Cooking	65%	2.0 kW	71%	1.6 kW
Convection oven, full- size	Gas	Cooking	30%	18000 Btu/h	46%	12000 Btu/h
Convection oven, half-size	Elec	Cooking	65%	1.5 kW	71%	1.0 kW
Conveyor oven > 25-inch belt	Gas	Cooking	20%	70,000 Btu/h	42%	57,000 Btu/h
Conveyor oven < 25-inch belt	Gas	Cooking	20%	45,000 Btu/h	42%	29,000 Btu/h
Fryer	Elec	Cooking	75%	1050 W	80%	1000 W
Fryer	Gas	Cooking	35%	14000 Btu/h	50%	9000 Btu/h
Griddle (based on 3' model)	Elec	Cooking	60%	400 W/ft2	70%	320 W/ft2
Griddle (based on 3' model)	Gas	Cooking	30%	3500 Btu/h/ft2	38%	2650 Btu/h/ft2
hot food holding	elec	cooking	na	40 W/ft3	na	21.5 V Watts

cabinets(excluding drawer warmers and heated display) $0 < V < 13\ ft^3$ (V = volume)						
hot food holding cabinets (excluding drawer warmers and heated display) $13 \leq V < 28\ ft^3$	elec	cooking	na	40 W/ft3	na	2.0 V + 254 Watts
hot food holding cabinets (excluding drawer warmers and heated display) $28\ ft^3 \leq V$	elec	cooking	na	40 W/ft3	na	3.8 V + 203.5 Watts
Large vat fryer	Elec	Cooking	75%	1350 W	80%	1100 W
Large vat fryer	Gas	Cooking	35%	20000 Btu/h	50%	12000 Btu/h
Rack oven, double	Gas	Cooking	30%	65000 Btu/h	50%	35000 Btu/h
Rack oven, single	Gas	Cooking	30%	43000 Btu/h	50%	29000 Btu/h
Range	Elec	Cooking	70%		80%	
Range	Gas	Cooking	5%	—	40% and no standing pilots	—
Steam cooker, batch cooking	Elec	Cooking	26%	200 W/pan	50%	135 W/pan
Steam cooker, batch cooking	Gas	Cooking	15%	2500 Btuh/pan	38%	2100 Btu/h/pan
Steam cooker, high production or cook to order	Elec	Cooking	26%	330 W/pan	50%	275 W/pan
Steam cooker, high production or cook to order	Gas	Cooking	15%	5000 Btuh/pan	38%	4300 Btu/h/pan
Toaster	Elec	Cooking	—	1.8 kW average operating energy rate	—	1.2 kW average operating energy rate
Ice machine, ice-making head, $H \geq 450$ lb/day	Elec	Ice	6.89 - 0.0011H kWh/100 lb ice	—	$37.72*H^{-0.298}$kWh/100 lb ice	—
Ice machine, ice-making head, $H \leq 450$ lb/day	Elec	Ice	10.26 – 0.0086H kWh/100 lb ice	—	$37.72*H^{-0.298}$kWh/100 lb ice	—
Ice machine RCU (w/o remote compressor) , $H < 1,000$ lb/day	Elec	Ice	8.85 - .0038H kWh/100lb ice	—	$22.95*H^{-0.258}$ + 1.00kWh/100 lb ice	—
ice machine RCU (remote condensing unit) $1600 > H \geq 1000$ lb/day	elec	ice	5.10 kWh/100lb ice	na	$22.95*H^{-0.258}$ + 1.00 kWh/100 lb ice	na

ice machine RCU (remote condensing unit) H ≥ 1600 lb/day	elec	ice	5.10 kWh/100lb ice	na	-0.00011*H + 4.60 kWh/100 lb ice	na
Ice machine self-contained unit, H < 175 lb/day	Elec	Ice	18.0 - 0.0469H kWh/100lb ice	—	$48.66*H^{-0.326}$ + 0.08kWh/100 lb ice	—
Ice machine self-contained unit, H ≥ 175 lb/day	Elec	Ice	9.80 kWh/100lb ice	—	$48.66*H^{-0.326}$ + 0.08kWh/100 lb ice	—
Ice machine, water-cooled ice- making head, H ≥ 1436 lb/day (must be on chilled loop)	Elec	Ice	4.0 kWh/100lb ice	—	3.68 kWh/100lb ice	—
Ice machine,	Elec	Ice	5.58 – 0.0011H	—	5.13 - 0.001H	—
water- cooled ice-making head, 500 lb/day < H > 1436 (must be on chilled loop)			kWh/100lb ice		kWh/100lb ice	
Ice machine, water-cooled ice- making head, H < 500 lb/day (must be on chilled loop)	Elec	Ice	7.80 – 0.0055H kWh/100 lb ice	—	7.02 - 0.0049H kWh/100 lb ice	—
Ice machine water-cooled once-through (open loop)	Elec	Ice	Banned	Banned	Banned	Banned
Ice machine, water-cooled self-contained unit, H < 200 lb/day (must be on chilled loop)	Elec	Ice	11.4 – 0.0190H kWh/100lb ice	—	10.6 - 0.177H kWh/100lb ice	—
Ice machine, water-cooled self-contained unit, H ≥ 200 lb/day (must be on chilled loop)	Elec	Ice	7.6 kWh/100lb ice	—	7.07 kWh/100lb ice	—
Chest freezer, solid or glass door	Elec	Refrig	0.45V + 0.943 kW/day	—	≤ 0.270 V + 0.130 kWh/day	—
Chest refrigerator, solid or glass door	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.125 V + 0.475 kWh/day	—
Glass-door reach-in freezer 0 ≤ V < 15 ft³	Elec	Refrig	.75V + 4.10 kWh/day	—	≤ 0.607 V + 0.893 kWh/day	—
Glass-door	Elec	Refrig	.75V + 4.10	—	≤ 0.733 V –	—

Chest freezer, solid or glass door	Elec	Refrig	0.45V + 0.943 kW/day	—	≤ 0.270 V + 0.130 kWh/day	—
Chest refrigerator, solid or glass door	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.125 V + 0.475 kWh/day	—
Glass-door reach-in freezer 0 ≤ V < 15 ft^3	Elec	Refrig	.75V + 4.10 kWh/day	—	≤ 0.607 V + 0.893 kWh/day	—
Glass-door	Elec	Refrig	.75V + 4.10	—	≤ 0.733 V –	—
reach-in freezer 15 ≤ V < 30 ft^3			kWh/day		1.00 kWh/day	
Glass-door reach-in freezer, 30 ≤ V < 50 ft^3	Elec	Refrig	.75V + 4.10 kWh/day	—	≤ 0.250 V + 13.50 kWh/day	—
Glass-door reach-in freezer, 50 ≤ V ft^3	Elec	Refrig	.75V + 4.10 kWh/day	—	≤ 0.450 V + 3.50 kWh/day	—
Glass-door reach-in refrigerator, 0 ≤ V < 15 ft^3	Elec	Refrig	.12V + 3.34 kWh/day	—	≤ 0.118 V + 1.382 kWh/day	—
Glass-door reach-in refrigerator, 15 ≤ V < 30 ft^3	Elec	Refrig	.12V + 3.34 kWh/day	—	≤ 0.140 V + 1.050 kWh/day	—
Glass-door reach-in refrigerator, 30 ≤ V < 50 ft^3	Elec	Refrig	.12V + 3.34 kWh/day	—	≤ 0.088 V + 2.625 kWh/day	—
Glass-door reach-in refrigerator, 50 ≤ V ft^3	Elec	Refrig	.12V + 3.34 kWh/day	—	≤ 0.110 V + 1.500 kWh/day	—
Solid-door reach in freezer, 0 ≤ V < 1 ft^3	Elec	Refrig	0.4V + 1.38 kWh/day	—	≤ 0.250 V + 1.25 kWh/day	—
Solid-door reach-in freezer, 15 ≤ V < 30 ft^3	Elec	Refrig	0.4V + 1.38 kWh/day	—	≤ 0.400 V – 1.000 kWh/day	—
Solid-door reach-in freezer, 30 ≤ V < 50 ft^3	Elec	Refrig	0.4V + 1.38 kWh/day	—	≤ 0.163 V + 6.125 kWh/day	—
Solid-door reach-in freezer, 50 ≤ V ft^3	Elec	Refrig	0.4V + 1.38 kWh/day	—	≤ 0.158 V + 6.333 kWh/day	—
Solid-door reach-in refrigerator, 0 ≤ V < 15 ft^3	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.089 V + 1.411 kWh/day	—
Solid-door reach-in refrigerator,	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.037 V + 2.200 kWh/day	—
15 ≤ V < 30 ft^3						
Solid-door reach-in refrigerator, 30 ≤ V < 50 ft^3	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.056 V + 1.635 kWh/day	—
Solid-door reach-in refrigerator, 50 ≤ V ft^3	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.060 V + 1.416 kWh/day	—
Clothes washer	Gas	Sanitatio n	1.72 MEF		2.00 MEF	
Door-type dish machine, high temp	Elec	Sanitatio n	—	1.0 kW	—	.70 kW

Door-type dish machine, low temp	Elec	Sanitatio n	—	0.6 kW	—	0.6 kW
Multitank rack conveyor dish machine, high temp	Elec	Sanitatio n	—	2.6 kW	—	2.25 kW
Multitank rack conveyor dish machine, low temp	Elec	Sanitatio n	—	2.0 kW	—	2.0 kW
Single-tank rack conveyor dish machine, high temp	Elec	Sanitatio n	—	2.0 kW	—	1.5 kW
Single-tank rack conveyor dish machine, low temp	Elec	Sanitatio n	—	1.6 kW	—	1.5 kW
Undercount er dish machine, high temp	Elec	Sanitatio n	—	0.9 kW	—	0.5 kW
Undercount er dish machine, low temp	Elec	Sanitatio n	—	0.5 kW	—	0.5 kW
Solid-door reach-in refrigerator,	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.037 V + 2.200 kWh/day	—
The energy efficiency, idle energy rates, and water use requirements, where applicable, are based on the following test methods:						

ASTM F1275 Standard Test Method for Performance of Griddles
ASTM F1361 Standard Test Method for Performance of Open Deep Fat
Fryers ASTM F1484 Standard Test Methods for Performance of Steam
Cookers ASTM F1496 Standard Test Method for Performance of Convection
Ovens ASTM F1521 Standard Test Methods for Performance of Range Tops
ASTM F1605 Standard Test Method for Performance of Double-Sided Griddles
ASTM F1639 Standard Test Method for Performance of Combination Ovens
ASTM F1695 Standard Test Method for Performance of Underfired Broilers
ASTM F1696 Standard Test Method for Energy Performance of Single-Rack Hot Water Sanitizing, ASTM Door-Type Commercial Dishwashing Machines
ASTM F1704 Standard Test Method for Capture and Containment Performance of Commercial Kitchen Exhaust Ventilation Systems
ASTM F1817 Standard Test Method for Performance of Conveyor Ovens
ASTM F1920 Standard Test Method for Energy Performance of Rack Conveyor, Hot Water Sanitizing, Commercial Dishwashing Machines
ASTM F2093 Standard Test Method for Performance of Rack Ovens
ASTM F2140 Standard Test Method for Performance of Hot Food Holding
Cabinets ASTM F2144 Standard Test Method for Performance of Large Open Vat
Fryers ASTM F2324 Standard Test Method for Prerinse Spray Valves
ASTM F2380 Standard Test Method for Performance of Conveyor Toasters
ARI 810-2007: Performance Rating of Automatic Commercial Ice Makers
ANSI/ASHRAE Standard 72–2005: Method of Testing Commercial Refrigerators and Freezers with temperature setpoints at 38°F for medium-temp refrigerators, 0°F for low-temp freezers, and -15°F for ice cream freezers

Door-type dish machine, low temp	Elec	Sanitatio n	—	0.6 kW	—	0.6 kW
Multitank rack conveyor dish machine, high temp	Elec	Sanitatio n	—	2.6 kW	—	2.25 kW
Multitank rack conveyor dish machine, low temp	Elec	Sanitatio n	—	2.0 kW	—	2.0 kW
Single-tank rack conveyor dish machine, high temp	Elec	Sanitatio n	—	2.0 kW	—	1.5 kW
Single-tank rack conveyor dish machine, low temp	Elec	Sanitatio n	—	1.6 kW	—	1.5 kW
Undercount er dish machine, high temp	Elec	Sanitatio n	—	0.9 kW	—	0.5 kW
Undercount er dish machine, low temp	Elec	Sanitatio n	—	0.5 kW	—	0.5 kW
Solid-door reach-in refrigerator,	Elec	Refrig	.1V + 2.04 kWh/day	—	≤ 0.037 V + 2.200 kWh/day	—
The energy efficiency, idle energy rates, and water use requirements, where applicable, are based on the following test methods:						

ASTM F1275 Standard Test Method for Performance of Griddles
ASTM F1361 Standard Test Method for Performance of Open Deep Fat
Fryers ASTM F1484 Standard Test Methods for Performance of Steam
Cookers ASTM F1496 Standard Test Method for Performance of Convection
Ovens ASTM F1521 Standard Test Methods for Performance of Range Tops
ASTM F1605 Standard Test Method for Performance of Double-Sided Griddles
ASTM F1639 Standard Test Method for Performance of Combination Ovens
ASTM F1695 Standard Test Method for Performance of Underfired Broilers
ASTM F1696 Standard Test Method for Energy Performance of Single-Rack Hot Water Sanitizing, ASTM Door-Type Commercial Dishwashing Machines
ASTM F1704 Standard Test Method for Capture and Containment Performance of Commercial Kitchen Exhaust Ventilation Systems
ASTM F1817 Standard Test Method for Performance of Conveyor Ovens
ASTM F1920 Standard Test Method for Energy Performance of Rack Conveyor, Hot Water Sanitizing, Commercial Dishwashing Machines
ASTM F2093 Standard Test Method for Performance of Rack Ovens
ASTM F2140 Standard Test Method for Performance of Hot Food Holding
Cabinets ASTM F2144 Standard Test Method for Performance of Large Open Vat
Fryers ASTM F2324 Standard Test Method for Prerinse Spray Valves
ASTM F2380 Standard Test Method for Performance of Conveyor Toasters
ARI 810-2007: Performance Rating of Automatic Commercial Ice Makers
ANSI/ASHRAE Standard 72–2005: Method of Testing Commercial Refrigerators and Freezers with temperature setpoints at 38°F for medium-temp refrigerators, 0°F for low-temp freezers, and -15°F for ice cream freezers

Table E-2: Supermarket refrigeration prescriptive measures and baseline for energy cost budget

Item	Attribute	Prescriptive measure	Baseline
Evaporator	Evaporator fan speed control	Variable-speed evaporator fan	Constant volume, constant operation
	Evaporator design approach temperature	10°F (-12°C)	10°F (-12°C)
Condenser	Air-cooled condenser fan speed control	Variable-speed condenser fan (electronically commutated motors if single phase and less than 1 hp (0.75 kW))	Cycling one-speed fan
	Air-cooled condenser design approach	Floating head pressure, min of 70°F (21°C), 5°F (3°C) drybulb offset	10°F to 15°F (-12°C to -9°C) depending on suction temperature
	Air-cooled condenser fan power	80 Btu/Watt-hr (84.4 kJ/ W-hr) at 10°F (-12°C) approach temperature	53 Btu/Watt-hr (55.9 kJ/ W-hr) at 10°F (-12°C) approach temperature
	Evaporative condenser fan speed control	Variable-speed condenser fan (electronically commutated motors if single phase and less than 1 hp (0.75 kW))	Cycling one speed fan
	Evaporative condenser design approach temperature	Floating head pressure, min of 70°F (21°C), 9°F (5°C) wetbulb offset	18°F (-13°C) to 25°F (-4°C) based on design wetbulb temperature
	Evaporative condenser fan and pump power	400 Btu/Watt-hr (422.1 kJ/W-hr) at 100°F (38°C) saturated condensing temperature and 70°F(21°C) wetbulb temperature	330 Btu/Watt-hr (348.3 kJ/ W-hr) at 100°F (38°C) saturated condensing temperature and 70°F (21°C) wetbulb temperature
Refrigeration system	Suction pressure control	Not addressed	Not addressed
	Condensing temperature control	85°F (30°C), minimum condensing temperature, fixed setpoint	85°F (30°C) minimum condensing temperature, fixed setpoint
	Defrost control	No electrical defrost, hot gas defrost only	Not addressed
Compressor	Compressor capacity modulation	Variable-speed drive trim compressor	Slide valves on screw compressors, multiple compressor racks on reciprocating compressor plants

Table E-3: Walk-in coolers and freezers prescriptive measures and baseline for energy cost budget

Item	Attribute	Prescriptive measure	Baseline
Envelope	Freezer insulation	R-46 (R-8.1 in (m^2-K/W))	R-36 (R-6.34 in (m^2-K/W))
	Cooler insulation	R-36 (R-6.34 in (m^2-K/W))	R-20 (R-3.52 in (m^2-K/W))
	Automatic closer doors	Yes	No
	High-efficiency low- or no-heat reach-in doors	40W/ft (130W/m) of door frame (low temperature), 17W/ft (55W/m) of door frame (medium temperature)	40W/ft (130W/m) of door frame (low temperature), 17W/ft (55W/m) of door frame (medium temperature)
Evaporator	Evaporator fan motor and control	Shaded pole and split phase motors prohibited; use PSC or EMC motors	Constant-speed fan
	Hot gas defrost	No electric defrosting.	Electric defrosting
Condenser	Air-cooled condenser fan motor and control	Shaded pole and split phase motors prohibited; use PSC or EMC motors; add condenser fan controllers	Cycling one-speed fan
	Air Cooled condenser design approach	Floating head pressure controls or ambient subcooling	10°F (-12°C) to 15°F (-9°C) dependent on suction temperature
Lighting	Lighting power density (W/sq.ft.)	0.6 W/sq.ft. (6.5 W/sq. meter)	0.6 W/sq.ft. (6.5 W/sq. meter)

Table E-4: Commercial kitchen ventilation prescriptive measures and baseline for energy cost budget

Strategies	Prescriptive measure	Baseline
Exhaust rate control	Demand control package	Constant volume